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TRADE STUDY FOR WATER AND WASTE MANAGEMENT CONCEPTS - TASK 7 SUPPORT SPECIAL ANALYSIS FINAL REPORT

MCDONNELL DOUGLAS ASTRONAUTICS COMPANY

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TRADE STUDY FOR WATER AND WASTE MANAGEMENT CONCEPTS - TASK 7 SUPPORT SPECIAL ANALYSIS FINAL REPORT

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PREFACE

This report is submitted to the National Aeronautics and Space Administration's Lyndon B. Johnson Space Center as the data requirement for Task 7, Support Special Analysis, Tradeoff of Water and Waste Management Concepts, contract NAS9-13404. The contract was performed under the direction of Mr. J. R. Jaax of Crew Systems Division. It presents evaluations of potential water and waste management concepts for use in the applications of Space Station, Lunar Surface Base and Interplanetary Missions. Additionally, the logic is provided in appendix form for computerized evaluation of candidate configurations. The contract was performed in the Biotechnology and Space Sciences Department by W. G. Nelson, task leader, with the assistance of W. Wong and M. M. Yakut.

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Section 1

INTRODUCTION AND SUMMARY

Many of the future space missions envisaged by today's planners will involve long-term support of man in earth orbit, on the lunar surface, and to the near planets. Success of these missions rely, in a large part, on the effectiveness of the life support systems to reliably provide the life support needs of the crew.

Earlier space ventures such as Gemini and Apollo relied on less complex, open systems for life support because of the relatively small crew sizes and short duration missions. Although Skylab was longer duration, the ample launch capability of the Saturn launch vehicle required life support systems of only medium efficiency.

As the day of longer duration missions approaches, however, more efficient and complex systems will be required which employ recovery of used crew waste products. Numerous different candidates exist for use in these long duration missions and several have received research and development effort to prove their worth and to arrive at workable designs. Several concepts have been proven by long-term testing with the crew included in the ecology loop and using their recovered waste.

The purpose of this study is to evaluate the numerous concepts and configurations which exist in the water and waste management area of life support. The concepts are evaluated from an equivalent weight and cost standpoint for the mission applications of Space Station, Lunar Surface Base and Interplanetary.

The results of the study can be divided into two categories: (1) results which identify the configuration characteristics having the biggest influence on equivalent weight and cost and (2) specific results on evaluations of candidate configurations. A summary of these results follows.

From a weight standpoint, expendables are the greatest contributor followed by equipment fixed weight, and equivalent power weight. Penalties for cooling are negligible. These conclusions apply to all three mission applications.

Referring to costs, hardware costs are the most important factor for applications of Lunar Base and Space Station. Launch costs due to fixed and expendable weights are the largest factors for Interplanetary flight.

Makeup water is required when recovery efficiency is not sufficiently high and this can contribute greatly to both cost and weight penalty.

Evaluations of the candidate configurations rely greatly on the concept characteristic data gathered from literature as reported in Section 3.1. Much of the data is conflicting and apparently was derived from dissimilar ground rules and requirements. Therefore, results of these evaluations are believed to only generally reflect the true worth of the configurations. It is recommended that effort be expended to refine the concept characteristics to a common base so that the evaluations can be made more meaningful.

However, based on the available data some general results can be summarized regarding the configuration evaluations. Vapor compression, flash evaporation and air evaporation with electrolytic pretreatment are favored for urine water recovery. Multifiltration appears superior to reverse osmosis for wash water recovery. The slinger/vacuum drying waste management concept had lower weight and cost than the vacuum drying with flush water. This did not reflect the potential esthetic value of the concept with flush water and the anal wash. The manner with which the above concepts are synthesized is not important as long as recovery techniques are sufficiently efficient to avoid makeup water.

The above results are highly dependent upon qualitative criteria which rank several potentially efficient concepts low because they are not well developed.

Appendix A presents detailed trade data to enable the reader to perform sensitivity analyses and to conveniently tradeoff system configurations not covered in the main body of this report.

Section 2

REQUIREMENTS

A comprehensive evaluation of possible water and waste management concepts requires clearly defined requirements for (1) crew requirements in terms of process rates, flow rates and water quality and (2) mission requirements in terms of vehicle and mission interfaces. Below the most important requirements are listed which have a significant influence on the trade study.

2.1 Crew Requirements

The water and waste management subsystem receives excreted and wash water from the crew and experiments and then treats, processes and stores the water until removal from the vehicle or reuse by the crew. Table 2-1 lists the key crew water needs.

Table 2-1

Crew Water Requirements

Item		Lb/Man-Day	Lb/6 Men-Day
Potable Water			
o Drinking		5.18	31.08
o Food Preparation (hot)		0.79	4.74
o Food Preparation (cold)		0.79	4.74
	Subtotal	6.76	40.56
Hygiene Water			
o Urine Flush Water (male urinal)		2.8	16.8
o Fecal Flush Water		3.3	19.8
o Shower Water		8.0	48.0
o Crewman Wash Water		4.0	24.0
o Washing Machine		36.7	220.0
o Utensils		15.0	90.0
	Subtotal	69.8	418.6
Experiment Water			5.0
	Total		464.16

Table 2-1

Crew Water Requirements
(Continued)

Item	Lb/Man-Day	Lb/6 Men-Day
Crew Output		
o Urine Liquid Output	4.4	
o Sweat Plus Insensible	4.02	
o Feces	0.07	
Other		
o Latent load from washers & showers		5.96
o Latent load from experiments		1.00
o Food preparation latent load		0.1

Note: Data Source - Preliminary Space Station Design Requirements for Environmental Thermal Control and Life Support System Equipment, MSC 01484.

2.2 Mission Requirements

Applications for the various candidate waste and water management configuration are (1) Space Station; (2) Lunar Surface Base; and (3) Interplanetary. Below, in Table 2-2, is a brief summary of the mission requirements used in the study.

Table 2-2

Mission Requirements

Item	Space Station	Lunar Base	Interplanetary
Mission duration, years	3 minimum	3 minimum	3 minimum
Number of crew	6	6	6
Electric power source	solar cells	isotope/Brayton	isotope/Brayton
Heat source	electrical	waste heat	waste heat
Cooling	space radiator	space radiator	space radiator
Launch vehicle	orbiter	orbiter, 2-stage chemical from earth orbit to lunar orbit, 2-stage chemical to lunar surface	gas core engine launcher
Resupply period	90 days	90 days	none
No. of flight units required	3	3	3

Isotope/Brayton power system was selected for the interplanetary mission because its penalties are nearly independent upon mission. Solar cell area is highly dependent upon the precise mission planned and the intent of the study was to investigate the interplanetary mission in general terms. Therefore, the isotope/Brayton power system was used for that application.

The number of flight units assumed was three. This allows for a backup unit and one equivalent unit for engineering models and qualification units.

2.3 DEFINE IMPACT CONSIDERATIONS

2.3.1 Introduction

Effort in task 2 involves the definition of the criteria to be used in evaluating the candidate water/waste management concepts. These criteria take the form of qualitative considerations and quantitative considerations (trade factors). The quantitative considerations attempt to reduce to some common quantity such as cost or equivalent weight all the physical characteristics of the candidates which impact the program. The qualitative considerations are those which are important in the comparisons but cannot be conveniently reduced to cost or weight. In the paragraphs below, the trade factors and qualitative considerations are given along with the rationale for their development. A summary of trade factors derived are given in Table 2-3.

2.3.2 Cost Trade Factor Development

The bulk of the data used to develop the trade factors originated in the Space Station Studies performed by McDonnell Douglas in the early 70's (contract NAS8-25140). Initial effort on the study was based on a Saturn launched large diameter Space Station. The study was later redirected to a Shuttle launched modular Space Station due to the maturation of the Shuttle program. Cost factors were developed during the study for both Space Station concepts. The Modular Space Station factors are applicable in this study for the Space Station application and cost data on the large diameter Space Station are useful for Interplanetary and Lunar Surface Base applications.

2.3.2.1 Space Station Cost Factors

Trade factors based on cost were derived by a linear extrapolation to updated shuttle launch costs. Cost per launch value used was $12.2 million/launch which is the value used on the MOSC study, Manned Orbital Systems Concepts (NAS8-31014), by NASA direction. Below is a table of Modular Space Station Factors along with extrapolated values for use with the Space Station application (see Reference 1).

Table 2-3

WATER AND WASTE MANAGEMENT

TRADE FACTORS

Application	Resource	Type: Cost	Type: Wt	Factor	Data Source
Space Station	Launch Weight	X		$610/Lb	Modular Space Station
	Launch Volume	X		$1,975/Cu Ft	Modular Space Station
	Electric Power (1)	X		$9,944/Watt-10 Yr	Modular Space Station
	Crew Time	X		$2,142/Man Hr	Modular Space Station
Lunar Surface Base	Launch Weight	X		$2340/Lb	Space Transportation System Data
	Launch Volume	X		$4359/Cu Ft	Modular Space Station
	Crew Time	X		$3110/Man Hr	Modular Space Station
	Electrical Power (2)	X		$13,597/Watt-10 Yr	Large Diameter Space Station
Interplanetary	Launch Weight	X		$12,287/Lb	Large Diameter S/S & Inhouse MDAC Studies
	Launch Volume	X		$32,002/Cu Ft	"
	Electrical Power (2)	X		$22,463/Watt-3 Yr	"
	Crew Time	X		$8,681/Man Hr	Modular Space Station

(1) Solar Cell/Battery

(2) Isotope/Brayton

Table 2-3

WATER AND WASTE MANAGEMENT

TRADE FACTORS

(Continued)

Application	Resource	Type: Cost	Type: Wt	Factor (lb)	Data Source
Space Station	Electrical Power (1)		X	$(0.372 + 0.238T)P$	Large Diameter Space Station
	Electrical Power (2)		X	$(0.344 + 0.118T)P$	Large Diameter Space Station
	Liquid Cooling		X	$(0.011 + 0.011P_p)Q$	Modular Space Station Data
	Air Cooling		X	$(0.0183 + 0.073P_p)Q$	Modular Space Station Data
Lunar Surface Base	Electrical Power (2)		X	$(0.35 + 0.118T)P$	Large Diameter Space Station
	Liquid Cooling		X	$(0.0123 + 0.012P_p)Q$	Modular Space Station
	Air Cooling		X	$(0.0196 + 0.074P_p)Q$	Modular Space Station
Interplanetary	Electrical Power (2)		X	$(0.341 + 0.118T)P$	Large Diameter Space Station
	Liquid Cooling		X	$(9.55 + 9.98\ P_p)\ Q \times 10^{-3}$	Modular Space Station
	Air Cooling		X	$(0.0169 + 0.072P_p)Q$	Modular Space Station

(1) Solar Cell/Battery

(2) Isotope/Brayton

Symbols

P - Power (watts)

T - Mission Duration (yr)

P_p - Power Penalty (lb/watt)

Q - Cooling (Btu/Hr)

COST TRADE FACTORS FOR SPACE STATION APPLICATION

Resource	Units	COST/LAUNCH $5x10^6$	$10x10^6$	12.2x10^6
Launch Weight	$/Lb	250	500	610
Launch Volume	$/cu ft	1,500	1,830	1,975
Electrical Power	$/watt-10 yr	7,650	8,590	9,944
Crew Time	$/man-hr	1,940	2,080	2,142

These trade factors are based on estimated changes in total program cost to add an increment of each resource.

2.3.2.2 Lunar Surface Base

Lunar Surface Base launch weight penalty was obtained by adding together the three major mission segments to move material from earth surface to lunar surface. The cost for earth surface to earth orbit was assumed to be the same as for the Space Station application. This assumption is valid if program costs for a Space Station are comparable to a lunar base, not counting transportation costs, and this is believed to be the case. Costs for transfer from earth orbit to lunar orbit and from lunar orbit to lunar surface came from reference 2 which is a recent study on transportation systems by NASA-MSFC.

In order to land 92.3×10^3 lbs of payload on lunar surface, it costs 1) \$$208.6 \times 10^6$ for the payload plus the propellant required for translunar and lunar landing, 2) \$$5.5 \times 10^6$ for the translunar vehicle cost per flight and 3) \$$1.85 \times 10^6$ for the lunar landing cost per flight. Therefore, the cost penalty for lunar surface base is:

$$\frac{\$\,208.6 \times 10^6 + \$5.5 \times 10^6 + \$1.85 \times 10^6}{92.3 \times 10^3 \text{ lbs payload}} = \$\,2340/\text{lb payload}$$

Type vehicles assumed for these calculations are (1) Shuttle for earth surface to earth orbit, (2) two stage chemical for earth orbit to lunar orbit and (3) single storage (chemical) for lunar orbit to lunar surface.

Other cost factors for the Lunar Surface Base were extrapolated from Modular Space Station data based on the value of $666/lb launch cost calculated above. This procedure assumes that the cost of the Lunar Base program would be similar to the Modular Space Station costs. Below is a table showing the extrapolated cost factors for Lunar Surface Base and the derivation of cost factor for isotope Brayton power. Modular Space Station data for solar cells was not extrapolated because the requirements for Lunar Base is much different; the long lunar night requires a second power source such as fuel cells.

		LAUNCH COST ($/LB)		
Resource	Units	250	500	2340
Launch Volume	$/cu ft	1500	1830	4359
Crew Time	$/man-hr	1940	2080	3110

The cost factor for isotope Brayton power source was also derived from Space Station data as follows:

$$\text{Power Cost (isotope Brayton)} = \frac{\text{hardware cost}}{\text{total power}} + \frac{\text{total launch weight}}{\text{total power}} \times \text{launch cost}$$

$$= \frac{\$228.3 \times 10^6}{25000 \text{ watts-10 yrs}} + \frac{47{,}700 \text{ lbs}}{25000 \text{ watts-10 yrs}} \times \$2340/\text{lb}$$

$$= \$13{,}597/\text{watt-10 yr}$$

2.3.2.3 Interplanetary Mission

Interplanetary missions differ from other applications in that (1) no resupply is possible, (2) fewer vehicles are involved, (3) launch weight is more critical and (4) large launch vehicles will probably be used. All of these considerations result in larger cost penalties.

Cost factors for interplanetary application were based on data from a recent inhouse study at MDAC and the Large Diameter Space Station study results. The cost of a 1996 manned Mars mission is estimated at $\$3.6\text{x}10^9$ and has a total payload capability of $293\text{x}10^3$ lbs. Therefore the launch cost is:

$$\text{Launch cost} = \frac{\$3.6 \times 10^9}{293 \times 10^3 \text{ lb}} = \$12{,}287/\text{lb}$$

Launch volume costs are obtained from Large Diameter Space Station data but modified for the different launch costs for interplanetary missions as follows:

$$\text{Volume cost} = \frac{\text{volume cost without launch cost}}{\text{total volume}} +$$

$$\frac{\text{structure weight}}{\text{total volume}} \times \text{launch cost}$$

$$= \frac{\$293.5 \times 10^6}{25{,}600 \text{ cu ft}} + \frac{42{,}790 \text{ lb}}{25{,}600 \text{ cu ft}} \times \$12{,}287/\text{lb} = \$32{,}002/\text{cu ft}$$

Electrical power cost was derived in the same manner as for Lunar Surface Base as follows:

$$\text{Power cost (Isotope Brayton)} = \frac{\text{hardware cost}}{\text{total power}} + \frac{\text{total launch weight}}{\text{total power}} \times \text{launch cost}$$

$$= \frac{\$228.3 \times 10^6}{25{,}000 \text{ watts-3 yr}} + \frac{27{,}120 \text{ lbs}}{25{,}000 \text{ watts-3 yr}} \times \$12{,}289/\text{lb}$$

$$= \$22{,}463/\text{watt-3yr}$$

The power penalty for solar cells was not developed because the penalty is highly dependent upon the specific mission flown. This is due to the change in solar energy value for missions nearer or farther away from the earth orbit around the sun. For instance, the solar cell area will change approximately by a factor of 4.4 between a Venus and a Mars mission. In order to hold the number of possible applications to a manageable number, a single type of power system design is assumed, namely the isotope Brayton design.

Crew time cost reflects the cost of resources necessary to sustain additional crew members for tending the subsystems. Since data is not available for the Large Diameter Space Station regarding the change in crew cost with changes in launch cost, the Modular Space Station data was used. Below is the extrapolation to Interplanetary mission applications.

CREW COST FACTOR EXTRAPOLATION FOR INTERPLANETARY APPLICATION

Launch cost, \$/lb	250	500	12,287
Crew Cost, \$/man hr	1,940	2,080	8,681

This high crew cost factor of \$3,681/man hr appears to be a high value compared to values of \$2,142/man hr for Space Station and \$2,173/man hr for Lunar Space Base. The high value is due mainly to the high launch costs associated with interplanetary flight.

2.3.3 Equivalent Weight Trade Factors

This paragraph describes the rationale and presents the results for power and heat rejection equivalent weight penalties for the various applications. Data was obtained by using Space Station study data for system weights associated with the resources of power and heat rejection.

2.3.3.1 Space Station Equivalent Weight Factors

The power weight factors for both solar cell/battery and isotope Brayton type designs were obtained from Reference 3 which studied the impact of adding small increments of power to the vehicle. The study also developed penalties for resupply of spares and this was included in the expression for power penalty. The solar array design consists of a rollout type of array with two axis gimballing and NiCd batteries. Below the resultant penalty factors are given.

Solar cells

Power penalty = (0.372 + 0.238T)P lbs

Isotope Brayton

Power penalty = (0.344 + 0.118T)P lbs

where

T - mission duration in years

P - power used in watts

Heat rejection penalties were developed by determining the incremented change in modular Space Station heat rejection weight for a small increase in heat rejection rate. Sufficient area is assumed to be available on the vehicle so that radiator weight penalty is due to tubes, manifolds and fluid. No penalty is included for structural weight and outer skin (fins). Scaling relationships for heat exchangers, pumps and related equipment was taken from Reference 4. The resultant penalty expressions are as follows:

Liquid cooling

Heat rejection penalty = $(0.011 + .011\ P_p)Q$ lbs

where

P_p - Power penalty in lbs/watt

Q - Cooling requirement in BTU/hr

Air Cooling

$$\text{Heat rejection penalty} = (0.0183 + 0.073\ P_p)Q$$

Design point for the radiator was taken as β angle of 90°, vehicle along the line-of-flight.

2.3.3.2 Lunar Surface Base Equivalent Weight Factors

Factors for this application were derived similar to those for the Space Station application except the penalties are slightly higher reflecting the larger radiator area required. Solar cells are not considered for power generation on the lunar surface because of the long lunar night when the solar cells are inoperative. Fuel cells could be used during this period but the penalties are expected to be larger than those for isotope Brayton designs. Design point for the radiator was taken as high noon.

Isotope Brayton Power

$$\text{Power penalty} = (0.35 + 0.118T)P \text{ lbs}$$

Liquid Cooling

$$\text{Cooling penalty} = (0.0123 + 0.012P_p)Q \text{ lbs}$$

Air Cooling

$$\text{Cooling penalty} = (0.0196 + 0.074P_p)Q \text{ lbs}$$

2.3.3.3 Interplanetary Equivalent Weight Factors

This application results in slightly lower penalties than Space Station because of the reduction in radiator area for deep space conditions. No modifications were made for change in solar heating constant for missions nearer or farther from the sun. This effect will not exist if the radiator axis points towards the sun and the effect will be only moderate if the vehicle is broadside to the sun since sun side portions of the radiator can

be made inactive. The design point used of earth distance from the sun and vehicle broadside to the sun is an intermediate design case.

Isotope Brayton power is the only power source presented since solar cell penalties are very dependent upon the mission flown. Solar cell area would be expected to vary by a factor of about 4.4 between a Venus and Mars mission. In order to hold the number of applications to a reasonable number, a single type of power system design is assumed for interplanetary, i.e., the isotope Brayton design.

The penalties are as follows:

Isotope Brayton Power

Power penalty = $(0.341 + 0.118T)P$ lbs

Liquid Cooling

Cooling penalty = $(9.55 \times 10^{-3} + 9.98 \times 10^{-3} P_P)Q$ lbs

Air Cooling

Cooling penalty = $(0.0169 + 0.072 P_P)Q$ lbs

2.3.4 Qualitative Criteria

Basis for the qualitative criteria is the Modular Space Station Study, see Reference 1. Definition of the criteria is modified somewhat however since their application is different from the Space Station Study. In that study it was desired to choose concepts which could be applied to a well defined program and schedule. The application in this program is different because the applications are not as precisely defined, a specific schedule is not defined and the results will be used for planning. Therefore, criteria such as development risk and status are not as important as performance, growth potential and flexibility. This also allows less developed concepts to be considered. Below is a list of qualitative criteria to be considered.

1. Performance
2. Safety
3. Development risk
4. Flexibility
5. Growth potential
6. Interface Sensitivity
7. Complexity

A brief explanation of how these criteria are applied is presented below.

Performance

All of the concepts to be traded will be scaled for the process needs of a 6 man crew. The performance criteria applies to performance beyond this such as (1) esthetic qualities to the crew, (2) quality of end product, (3) noise level, and (4) convenience of use.

Safety

Some candidate concepts may be inherently unsafe due to (1) use of toxic materials, (2) potential for contaminating other systems or the environment, (3) use of explosive materials or (4) high pressure fluids. A design will not be considered unsafe if it can be rendered safe by relatively simple design modifications.

Development Risk

This criteria is used to credit concepts which have received significant development thereby enabling their potential to be more precisely determined. Therefore more confidence exists that a good assessment can be made regarding the probability of the concepts being successfully incorporated into a vehicle design.

Flexibility

This criteria is particularly important in this study because several applications are being considered. Therefore, a concept which is flexible to accommodate a variety of applications and alternate missions requirements is a particularly good candidate for concentrated development effort.

Growth Potential

Growth potential is important for the same reason as flexibility. Concepts which have good growth potential have a greater possibility of ultimately returning more for the initial development investment. Theoretical capability when compared to performance of current development models will aid in growth potential assessment.

Interface Sensitivity

Concepts which are sensitive to interface changes have the disadvantage of becoming less effective or obsolete if the vehicle interfaces change. For example, if a water recovery concept relies on waste heat being available at a high temperature and low penalty, the concept may look attractive when used with an isotope Brayton power system. However, if the vehicle of application changes and solar cell power is used, then substantial penalties may result to provide the heat electrically or with a solar collector. A concept which is less sensitive to power system would be favored with regard to interface sensitivity.

Complexity

Less complex concepts generally have an advantage because of inherent reliability, lower cost, ease of testing and maintenance and lower development risk. These are only general trends and complexity will be considered in conjunction with reliability, spares requirements, and crew maintenance time.

Section 3

CONCEPT DEFINITION

In this section the basic data for water and waste management concepts are described, the procedures to extrapolate the data to specific studies are discussed, and the candidate configurations for evaluation are defined.

3.1 Data Collection

The most promising water and waste management systems applicable to manned orbital, lunar and interplanetary space flight systems were evaluated. System characteristics were obtained from both NASA and MDAC reports, as well as from hardware manufacturers' development and test data reports. The systems evaluated are indicated in Table 3-1, which also shows the type of wastes processed in each system and the name of the unit's primary manufacturer.

Table 3-1

Candidate Water and Waste Management Systems

System/Process	Type of Processed Waste	Primary Manufacturers
Vapor Compression Distillation	urine, fecal water, condensate, wash water	Chemtric, Inc.
Air Evaporation/ Electrolytic Pretreatment	urine	MDAC
Air Evaporation/ Chemical Pretreatment	urine	MDAC
Reverse Osmosis	wash water	Abcor, Envirogenics, General Electric
Multifiltration	wash water	MDAC
Vapor Diffusion	urine	Hamilton-Standard
Electrodialysis	urine, wash water	Ionics, Incorporated
Flash Evaporation	urine, wash water	AiResearch
Wet Oxidation	urine, wash water, feces, trash	Whirlpool, GE, Lockheed

Table 3-1

Candidate Water and Waste Management Systems
(Continued)

System/Process	Type of Processed Waste	Primary Manufacturers
RITE	urine, wash water, feces	GE
Bag/Storage Waste Management	feces	Whirlpool, Rockwell, Fairchild
Waste Vacuum Drying	feces	Fairchild
Slinger Type Waste Management	feces	GE
Vacuum Drying Water Flush Waste Management	feces	Hamilton-Standard

3.2 Data Normalization

Flight concept data presented in Table 3-2 are for various systems of various sizes and process rates. In this comparative study, these systems are scaled to the boundary conditions specified by the missions under consideration. The following example illustrates how the systems were scaled. The scaling equations are from Reference 22. Not all the systems considered are treated in the reference; for these concepts, equation forms were used for concepts of similar design. Only the equation forms were used; the equations were not used to size the concepts directly. To illustrate the application of these scaling equations, the vapor compression calculation will be presented as a sample calculation.

(a) Process rate is taken from the mass balance, e.g., 43.2 lb/day.

(b) Equipment weight equation comes from Reference 22's system weight equation. Only the fixed weight constant and the exponent are assumed to be the same. The new constant is calculated from the latest available equipment data.

$$640 \text{ lb} = 5.4 \times 2.2 + K_w(\bar{W})^{0.475}$$

where K is the constant to be determined and $\bar{W}$ is the process rate.

TABLE 3.2. CANDIDATE WATER AND WASTE MANAGEMENT CONCEPT EVALUATION

CONCEPT	PROCESSED MATERIALS (1)	PROCESS RATE	CREW SIZE	EQUIPMENT WEIGHT LBS	EQUIPMENT VOLUME CU FT	EXPENDABLES LBS/DAY	INITIAL SPARES LBS/DAY	MAKEUP SPARES LBS/DAY	WATER RECOVERY FRACTION	RELIABILITY LEVEL (2)	CREW TIME (2)	ELECTRIC POWER		COST $ MILLIONS			REFERENCES
												WATTS AC	WATTS DC	NON-REC.	RECURRING	SPARES & EXPEND.	
Vapor Compression Distillation	U, FW, C	131.4 lbs/day	6	640	18	28/90	129/90	60/90	0.969	M	L	377		7.6	2.3	0.4	5, 6, 7
Air Evaporation with Electrolytic Pretreatment	"	69.4 lbs/day	6	895	48.8	190/ 180	460/ 180	306/ 180	0.95	H	L	390	600 + 700 heat	9.8	1.1	0.49	8, 9, 10
Air Evap - Chemical Pretreatment	U	88.53 lbs/day	6	295	35	250/ 180	160/ 30	40/30	0.95	H	L	420	20 + 830 heat	4.18	1.2	0.44/ 90	18
Reverse Osmosis	WW	224 lbs/day	6	240	6.6	143/ 90	100/ 90	46/90	0.968	H	L	220	20	6.9	0.7	0.75	6, 7, 11, 12, 13, 14
Multifiltration	WW	164 lbs/day	6	198	9.9	178/ 180	34/ 180	23/ 180	0.985	H	L	10	20	3.3	.57	.11	7, 15, 16, 17, 18
Vapor Diffusion	U	223 lbs/day	9	459	13.1	199/ 500	112/ 500	112/ 500	0.96	L	H	1920	20	5.19	0.85	1.54	18, 19, 20
Electrodialysis	U, WW	82 lbs/day	10	136	3.9	958/ 360	123/ 360	82/ 360	0.95	M	M	20	21	7.5	2.4	0.9	21, 22, 23

NOTES: (1) U = URINE, FW = FLUSH WATER, WW = WASH WATER, C = CONDENSATE, F = FECES

(2) H = HIGH, M = MEDIUM, L = LOW

(3) REFERENCES: ATTACHED

Table 3.2 (Cont) CANDIDATE WATER AND WASTE MANAGEMENT CONCEPT EVALUATION

CONCEPT	PROCESSED MATERIALS (1)	PROCESS RATE	CREW SIZE	EQUIPMENT WEIGHT LBS	EQUIPMENT VOLUME CU FT	EXPENDABLES LBS/DAY	INITIAL SPARES LBS/DAY	MAKEUP SPARES LBS/DAY	WATER RECOVERY FRACTION	RELIABILITY LEVEL (2)	CREW TIME (2)	ELECTRIC POWER WATTS AC	ELECTRIC POWER WATTS DC	COST $ MILLIONS NON-REC.	COST $ MILLIONS RECURRING	COST $ MILLIONS SPARES & EXPEND.	REFERENCES
Flash Evaporation	U, WW	60 lb/day	3	258	7.4	14.6/ 90	104/ 90	70/ 90	0.95	M	M	-	450	6.4	1.6	0.8	24
Wet Oxidation	U, WW, F	62 lb/day	6	264	22.5	360/ 360	176/ 360	120/ 360	0.95	L	H	345	20	8.0	2.0	0.75	25, 26, 27
RITE	U, WW, F	60.4 lb/day	4	910	26	360/ 360	616/ 360	410/ 360	0.975	L	H	360	30	10.6	2.3	0.95	7, 28, 29, 30
Bag/Storage Waste Management System	F	2 lb/day	6	192	12	246/ 90	19/ 90	5/ 90	-	H	H	-	4	2.3	1.76	0.14	22
Vacuum Drying Waste Management System	F	2 lb/day	6	251	14	57/ 90	34/ 90	5/ 90	-	M	M	-	8	4.8	1.1	0.3	
Slinger Type Waste Management	F	1.3 lb/day	4	95	8	76/ 180	45/ 400	30/ 400	-	H	L	400	-	3.2	0.35	0.1	15
Vacuum Dry Water Flush (SSP)	F		6	309	43	41/ 180	54/ 180	5/ 90	-	H	L	101	107	2.7	1.6	0.2	13

NOTES: (1) U = URINE, FW = FLUSH WATER, WW = WASH WATER, C = CONDENSATE, F = FECES

(2) H = HIGH, M = MEDIUM, L = LOW

(3) REFERENCES: ATTACHED

$$K_w = 61.9$$

$$\text{System equipment weight} = 11.8 + 61.9\ (43.2)^{0.475} = 382\ \text{lb}$$

Similarly, the volume equation is

$$\text{Vol.} = 35.2 \times 4.25 \times 10^{-2} + K_v(131.4) = 18\ \text{cu ft}$$

$$K_v = 0.126$$

System equipment volume for a process rate of 43.2 lb/day is

$$V = 1.496 + 0.126\ (43.2) = 6.94\ \text{ft}^3$$

Note: The constants 2.2 and 35.2 in the above equations convert the results from metric to English units.

- System power is assumed to be directly proportional to process rate:

$$\text{Power Required} = \left(\frac{43.2\ \text{lb/day}}{131.4\ \text{lb/day}}\right) \times 377\ \text{watts} = 124\ \text{watts}$$

- Expendables are assumed to be proportional to process rate:

$$\left(\frac{43.2}{131.4}\right) \times \frac{28\ \text{lbs}}{90\ \text{days}} = 9.2\ \frac{\text{lb}}{90\ \text{days}}$$

- The initial and makeup spares are proportional to the fixed weights.

$$\text{initial spares} \quad \frac{382\ \text{lb}}{640\ \text{lb}} \times \frac{129\ \text{lb}}{90\ \text{days}} = \frac{77\ \text{lb}}{90\ \text{days}}$$

$$\text{makeup spares} \quad \frac{382\ \text{lb}}{640\ \text{lb}} \times \frac{60\ \text{lb}}{90\ \text{days}} = \frac{36\ \text{lb}}{90\ \text{days}}$$

- Crew time is taken from SSP report where available. Otherwise, it is estimated from a similar system.

- It is assumed that the non-recurring, recurring, spares and expendables costs are unchanged.

A summary of the performance characteristics of each of the systems evaluated is presented in Table 3-3. Included are 1) the processed material types and rates; 2) equipment weight, volume, initial spares and power requirements; 3) resupply spares and expendable as a function of resupply times; 4) qualitative assessment of reliability level and crew time; and 5) cost.

All weight, volume and power characteristics were based on manufacturers' estimated flight equipment configurations. Some of the manufacturers' data, which included detailed system analyses, resulted in identifying more components for redundancy, valving and fluid routing, and consequently entailed higher system weights than others. No effort was made in this study to normalize the effects of such variations in system design sophistication.

The amounts of spares required, when not explicitly given in the manufacturers' reports, were calculated by using the spares provisioning calculation method presented in Reference 22.

Reliability levels and crew maintenance times were qualitatively evaluated for each system and assessed as high, medium or low.

Cost estimates were also established for each of the concepts evaluated. Cost values are shown in Table 3-3 for non-recurring, recurring and spares and expendables. Most of the cost estimates were calculated from the data and methodology presented in References 7 and 18. All costs are given in 1975 dollars. A factor, equivalent to cost of living index, was used to account for escalation in costs due to inflation.

3.3 Mass Balance

A water mass balance was produced in order to translate the water production and use data from Section 2 into performance requirements for the candidate waste and water management configurations. This mass balance also determines the makeup water requirements for the candidate configurations so that the differences in recovery efficiencies can be accounted for.

Table 3-3 CANDIDATE WATER AND WASTE MANAGEMENT CONCEPT EVALUATION

CONCEPT	PROCESSED MATERIALS (1)	PROCESS RATE	CREW SIZE	EQUIPMENT WEIGHT LBS	EQUIPMENT VOLUME CU FT	EXPENDABLES LBS/DAY	INITIAL SPARES LBS/DAY	MAKEUP SPARES LBS/DAY	WATER RECOVERY FRACTION	RELIABILITY LEVEL (2)	CREW TIME (2)	ELECTRIC POWER WATTS AC	ELECTRIC POWER WATTS DC	COST $ MILLIONS NON-REC.	COST $ MILLIONS RECURRING	COST $ MILLIONS SPARES & EXPEND.
Vapor Compression	U U + FW U + WW All	43.2 64.2 430.9 452	6	382 459 1116 1141	6.94 9.59 56 58	9.2/90 13.7/90 40/90 43/90	77/90 92.5/90 225/90 260/90	36/90 43/90 105/90 107/90	0.969	M	152 MH/Yr	124 184 1238 1298		7.6	2.3	0.4
Air Evaporation with Electrolytic Pretreatment	U	43.2	6	728	37	118/180	340/180	226/180	0.95	H	475 MH/3 Yr	246	410 +436 Heat	9.8	1.1	0.49
Air Evaporation with Chemical Pretreatment	U	43.2	6	208	23	122/180	113/30	28/30	0.95	H	499 MH/3 Yr	210	10 +429 Heat	6.7	1.0	.44/90
Reverse Osmosis	WW	387.7	6	368	8.9	248/90	173/90	80/90	0.968	H	185 MH/Yr	135	20	6.9	0.7	0.75
Multifiltration	WW	387.7	6	379	17.5	421/180	65/180	44/180	0.985	H	249 MH/Yr	10	34	3.3	0.57	0.11
Vapor Diffusion	U	43.2	6	153	4.8	38.6/500	37/500	37/500	0.96	H	345 MH/3 Yr	800	4	5.19	0.85	1.54
Electrodialysis	U U + WW	43.2 430.9	6 6	92 495	2.8 24	504/360 2317/360	21/90 113/90	13.9/90 74/90	0.95	M	315 MH/3 Yr	14 95	14 100	7.5	2.4	0.9

NOTES: (1) U = URINE, FW = FLUSH WATER, WW = WASH WATER, C = CONDENSATE, F = FECES

(2) H = HIGH, M = MEDIUM, L = LOW

(3) REFERENCES: ATTACHED

Table 3-3 (Cont) CANDIDATE WATER AND WASTE MANAGEMENT CONCEPT EVALUATION

CONCEPT	PROCESSED MATERIALS (1)	PROCESS RATE	CREW SIZE	EQUIPMENT WEIGHT LBS	EQUIPMENT VOLUME CU FT	EXPENDABLES LBS/DAY	INITIAL SPARES LBS/DAY	MAKEUP SPARES LBS/DAY	WATER RECOVERY FRACTION	RELIABILITY LEVEL (2)	CREW TIME (2)	ELECTRIC POWER WATTS AC	ELECTRIC POWER WATTS DC	COST $ MILLIONS NON-REC.	COST $ MILLIONS RECURRING	COST $ MILLIONS SPARES & EXPEND.
Flash Evaporation	U U+WW	43.2 430.9	6 6	207 975	6.1 25	10.5/90 42/90	83/90 393/90	56/90 265/90	0.95	M	232 MH/3 yr	0	327 1673	6.4	1.6	0.8
Wet Oxidation	U U+FW U+WW All	43.2 64.2 430.9 452	6	207 270 976 1008	18.1 23.1 74 76.2	252/360 375/360 1002/360 1051/360	138/360 180/360 651/360 672/360	94/360 122/360 443/360 457/360	0.95	L	230 MH/Yr	245 359 2338 2452	14 21 139 145	8.0	2.0	0.75
RITE	U U+FW U+WW All	43.2 64.2 430.9 452	6	725 951 3449 3564	21 27 87 89.6	257/360 384/360 1027/360 1138/360	492/360 644/360 2335/360 2413/360	328/360 428/360 1553/360 1605/360	0.975	L	228 MH/3 yr	260 383 2496 2629	22 32 213 224	10.6	2.3	0.95
Bag/Storage Waste Management System	F	2 lb/day	6	192	12	246/90	19/90	5/90	-	H	H	-	4	2.3	1.76	0.14
Bag/Vacuum Drying Waste Management System	F	2 lb/day	6	251	14	57/90	34/90	5/90	-	M	M	-	8	4.8	1.1	0.3
Slinger/Vacuum Drying Waste Management System	F	1.3 lb/day	4	95	8	76/180	45/400	30/400	-	H	L	400	-	3.2	0.35	0.1
Vacuum Dry Water Flush	F		6	309	43	41/180	54/180	5/90	-	H	L	101	107	2.7	1.6	0.2

NOTES: (1) U = URINE, FW = FLUSH WATER, WW = WASH WATER, C = CONDENSATE, F = FECES

(2) H = HIGH, M = MEDIUM, L = LOW

(3) REFERENCES: ATTACHED

An important interface when determining the makeup water requirements involves the interface with the O_2 recovery system. In performing the mass balance, an O_2 recovery system was assumed to be part of the vehicle system; the type assumed employs 1) electrochemical depolarized CO_2 concentrator, 2) Sabatier O_2 recovery and 3) water electrolysis for O_2 supply.

The typical mass balance written in terms of generalized efficiencies is shown in Figure 3-1. Also, two types of fecal collectors are shown, with and without flush. Condensate which is relatively pure water was used for urinal flush; excess condensate beyond this requirement was directed to the wash water system where it can be processed at lower penalty than in the urine water recovery system.

Water flows to the cabin in the form of water vapor from washers, shower and experiments and this is made up by the condensate and makeup water from potable water storage. The O_2 recovery system requires 16.38 lb/day of water flow for water electrolysis; this is obtained by using condensate. Water vapor is ejected into the cabin from the electrochemical depolarized CO_2 concentrator at the rate of 7.81 lbs/day. Water is lost overboard due to atmosphere leakage, 0.102 lb/day, and from the Sabatier reactor, 0.473 lb/day.

Water makeup is required in the water balance if overall water recovery efficiency is less than 97.9% with fecal flush and 98.06% without fecal flush. The higher percentage is due to water recovery assumed from fecal water.

3.4 Water Recovery Versus Stored Water Trade

A preliminary task to evaluating water recovery concepts is to determine if indeed water recovery is merited at all. This paragraph describes a trade which was performed from an equivalent cost and weight standpoint of water recovery versus stored water. The water recovery configuration considered uses the following concepts:

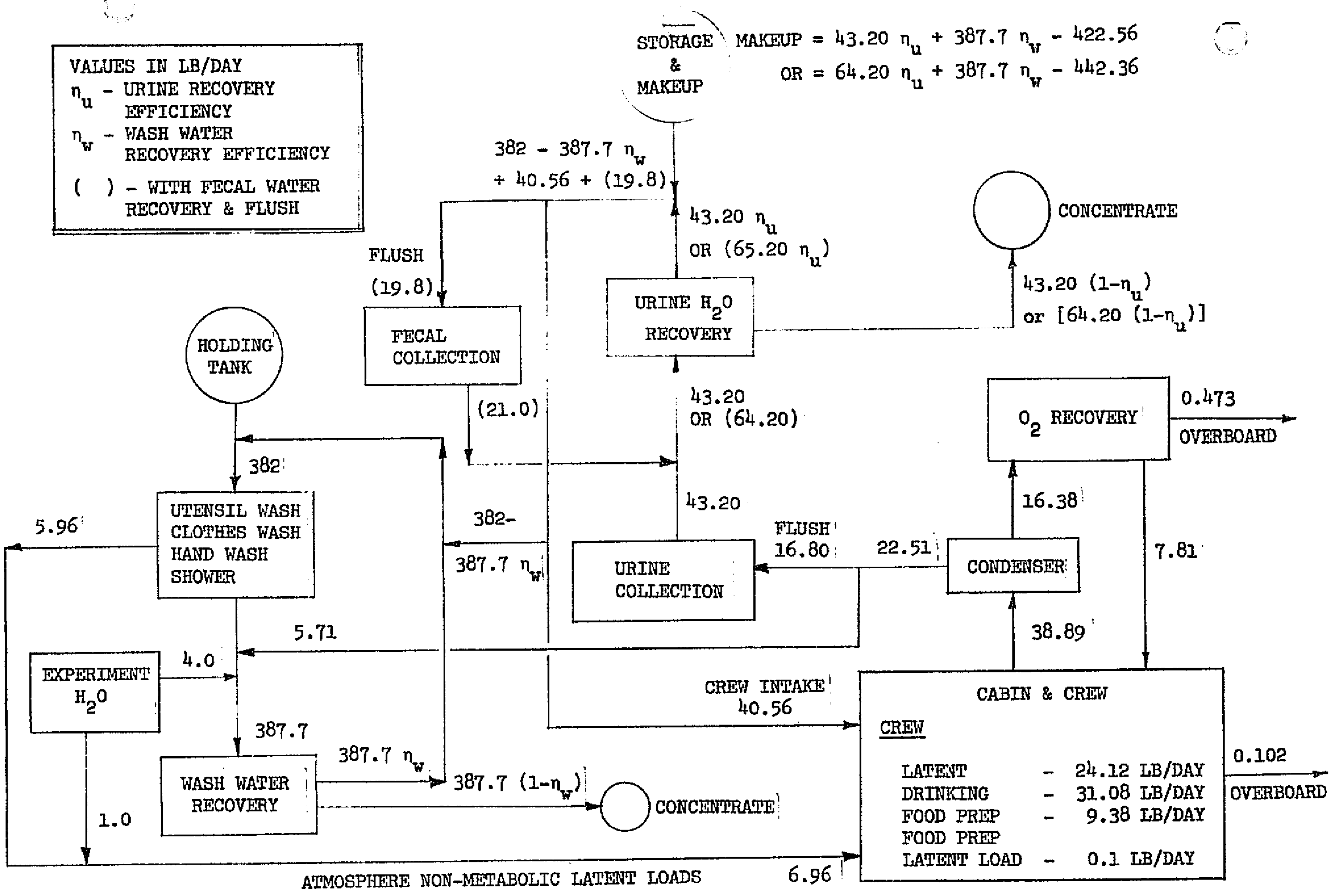

FIGURE 3-1. WATER BALANCE FOR WATER RECOVERY CONCEPT

- Urine water recovery - vapor compression
- Wash water recovery - reverse osmosis
- Makeup water storage - bladdered tanks

The Space Station application was used in the trade because this application should be least favorable to water recovery because of the lower penalties associated with costs for resupply weight and volume, electrical power and crew time. Weight penalties for power and cooling are slightly higher due to equivalent weight of solar cell power, however, the effect of these penalties are small. Therefore, if water recovery traded favorably for Space Station application it would also be favored for Lunar Base and Interplanetary mission.

Two sets of bladdered tanks are assumed for this stored water concept. This assumption is valid whether the water is stored on the Space Station or a logistics module. If the water is stored on the Space Station a second tank set is required in the logistics module for bringing up resupply water. If the water is kept in a docked logistics module, a second tank set is required when the docked logistics module is replaced. Sufficient tankage is provided for 90 day water supply.

Figures 3-2 and 3-3 show the trade results for equivalent weight and cost respectively. Based on the water requirements of 378.9 lb/day a tremendous amount of resupplied water is required over a 3 year period. This amounts to 409,000 lbs for the rather large water requirement based on Reference 31. Water recovery is highly favored based on weight, saving over 400,000 lbs resupply in three years.

Water recovery is highly favored from an equivalent cost standpoint also as seen from Figure 3-3. Water recovery costs nearly 30.0 million dollars more initially but after about 5 months is less costly than stored water. At the end of three years, water recovery will save about 205 million dollars.

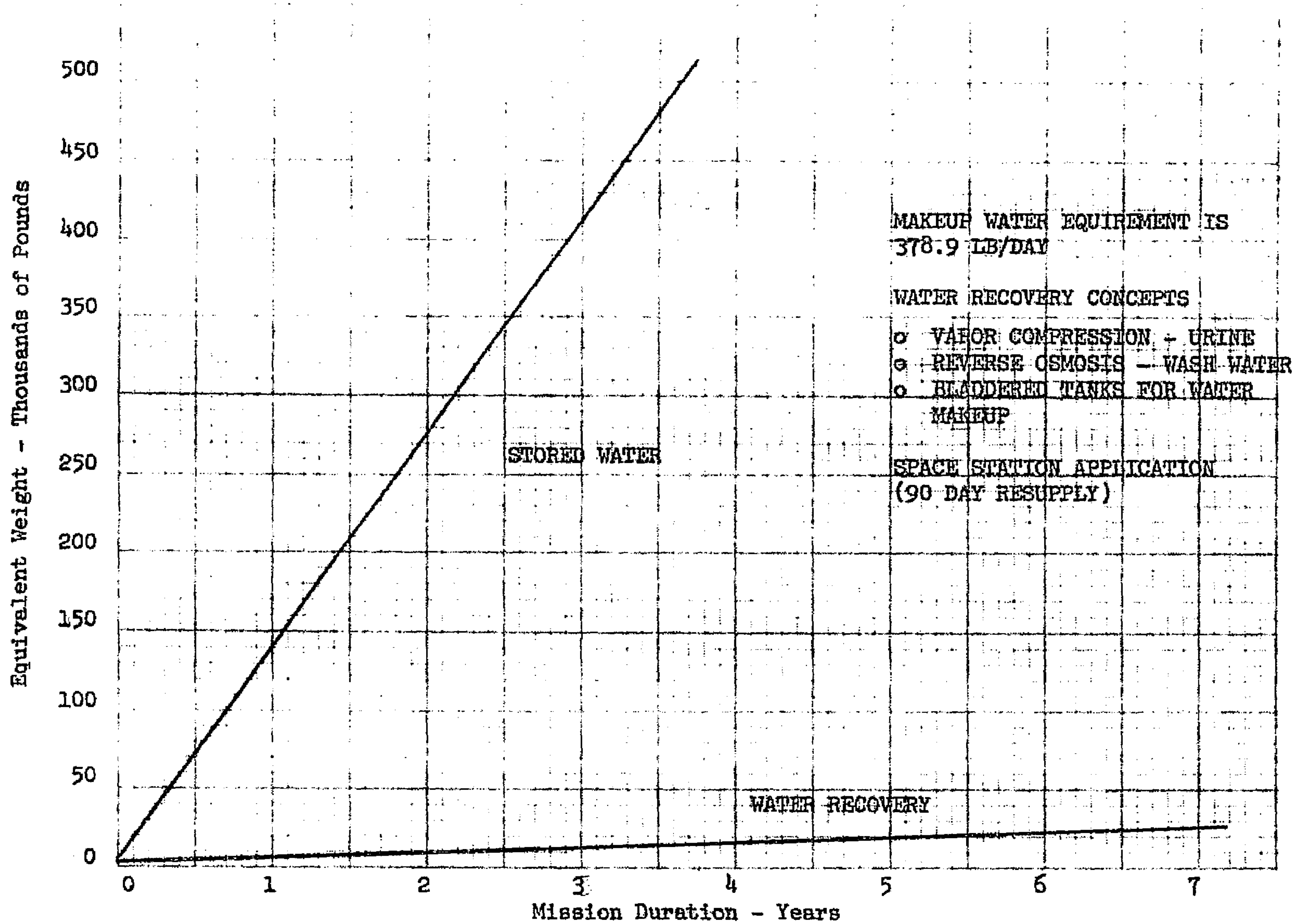

FIGURE 3-2 WATER RECOVERY VERSUS STORED WATER - WEIGHT TRADEOFF

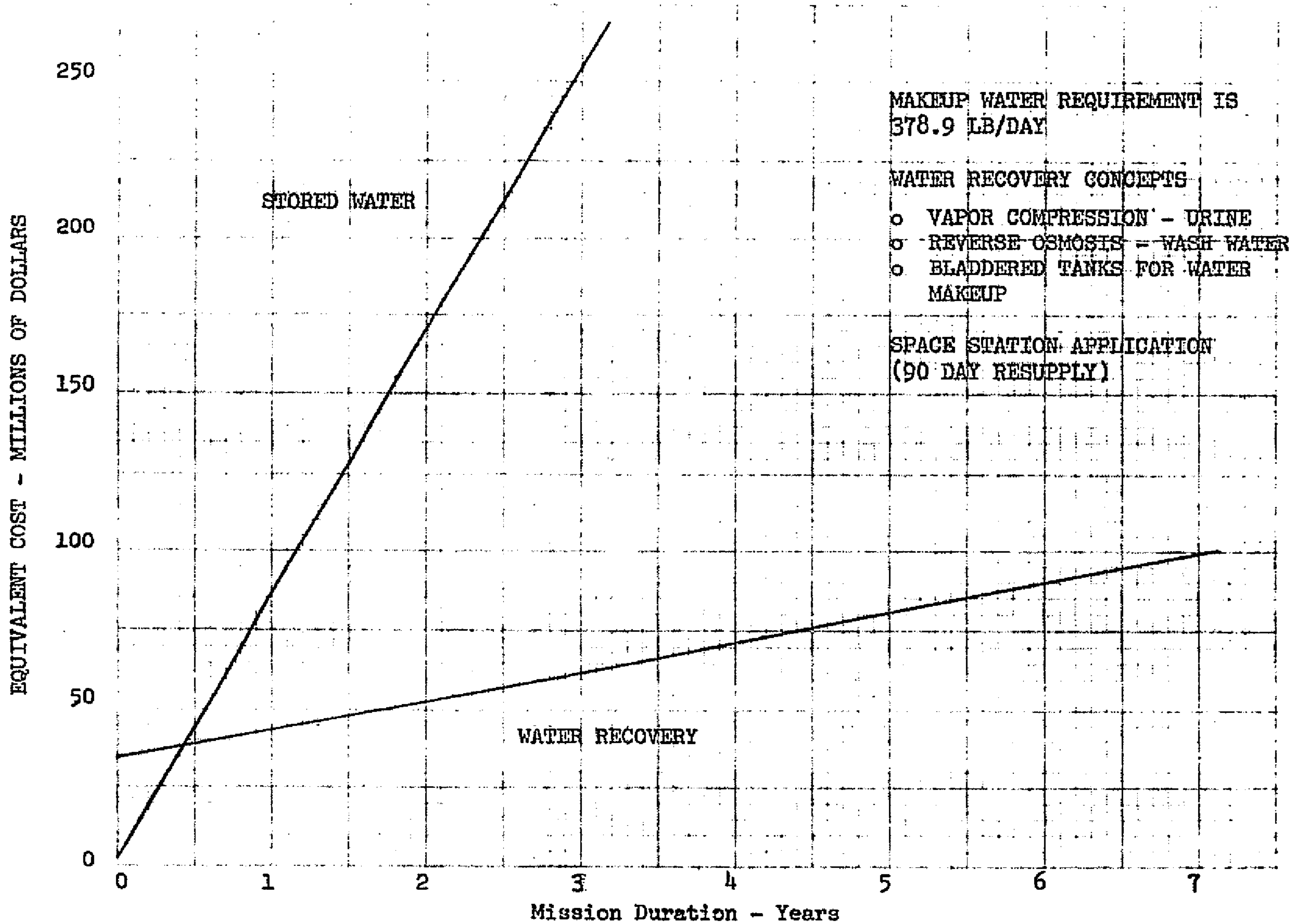

FIGURE 3-3 WATER RECOVERY VERSUS STORED WATER - COST TRADEOFF

The trade discussed above assumes urine, wash, condensate and experiment water recovery. Urine water recovery is far more costly from a weight and cost standpoint and it is logical to consider eliminating urine water recovery and resupplying the additional water required. This was examined and it was determined the urine water recovery alone would save about 7 million dollars and reduce resupply weight by about 42,000 lbs over 3 years. Therefore it is adviseable to employ water recovery from all sources.

3.5 Generation of Configurations Employing Water Recovery

Due to the unmanageable number of possible combinations of water and waste management configurations, it is impractical to examine all possible combinations. Choosing configurations by examination of concept characteristics from Table 3-3 is not effective because of the large number of parameters involved and insufficient visability on their effect on weight and cost.

A more precise method is to perform trade studies to select the most competitive individual concepts from a weight, cost, and qualitative standpoint. This was done for the 3 major concept functions, i.e., 1) urine water recovery, 2) wash water recovery and 3) waste management. Trade factors and qualitative criteria used for these trades are those derived in Section 2.3. The results of these trades are shown in Figures 3-4 to 3-23 and Table 3-4.

Urine water recovery concept weight trades are shown in Figures 3-4 to 3-6. Electrodialysis is the lowest initial weight concept for all 3 applications. Vapor diffusion, vapor compression, flash evaporation and wet oxidation have low overall weight advantages.

Figures 3-7, 3-8 and 3-9 show the cost tradeoff for urine water recovery. Space Station low cost concepts are vapor diffusion, flash evaporation and wet oxidation. Flash evaporation, vapor diffusion, vapor compression, and electrodialysis are low overall cost concepts for Lunar Base. Vapor compression, flash evaporation and vapor diffusion are lowest cost for Interplanetary Missions.

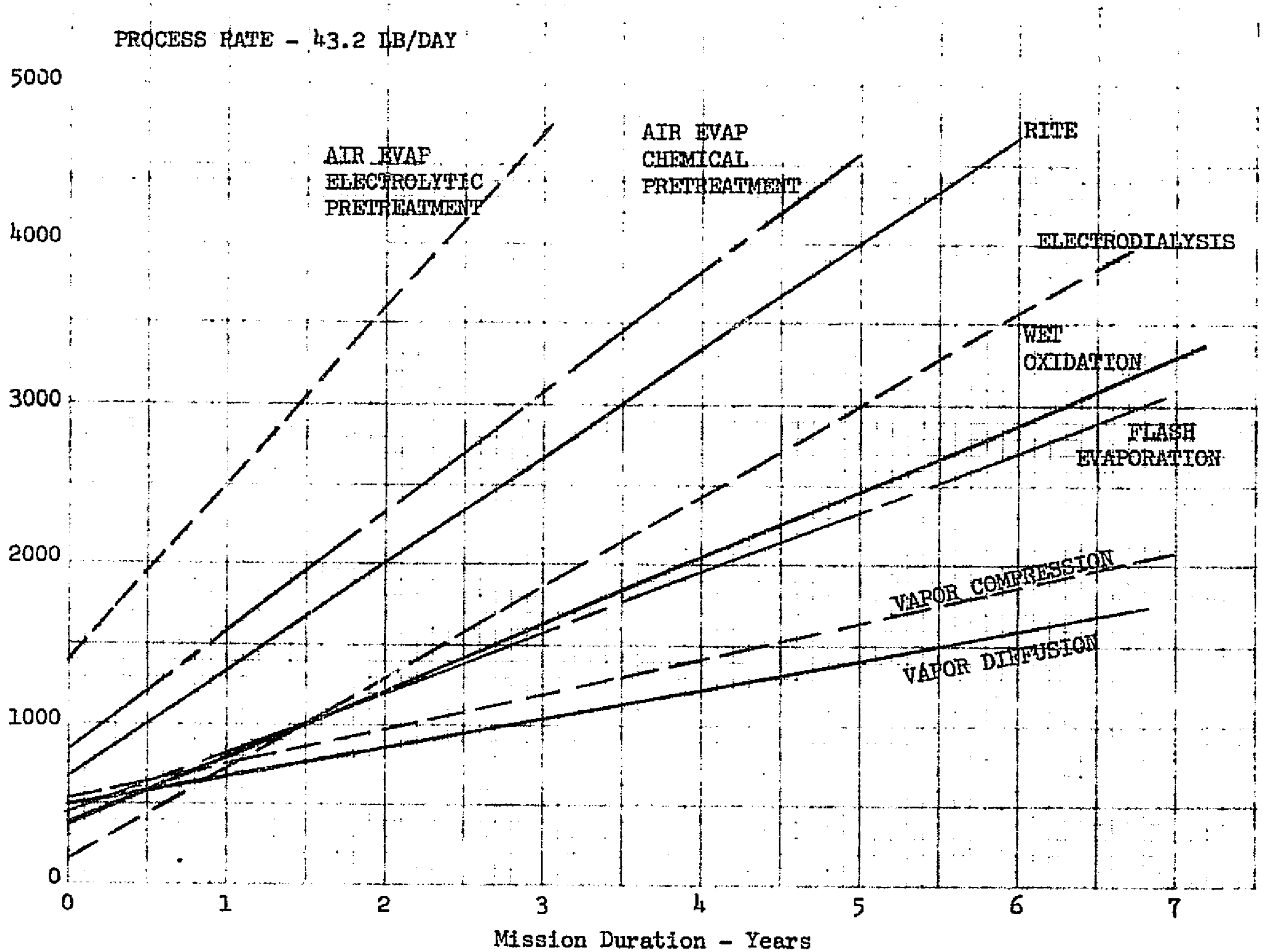

FIGURE 3-4. URINE WATER RECOVERY WEIGHT TRADE - SPACE STATION

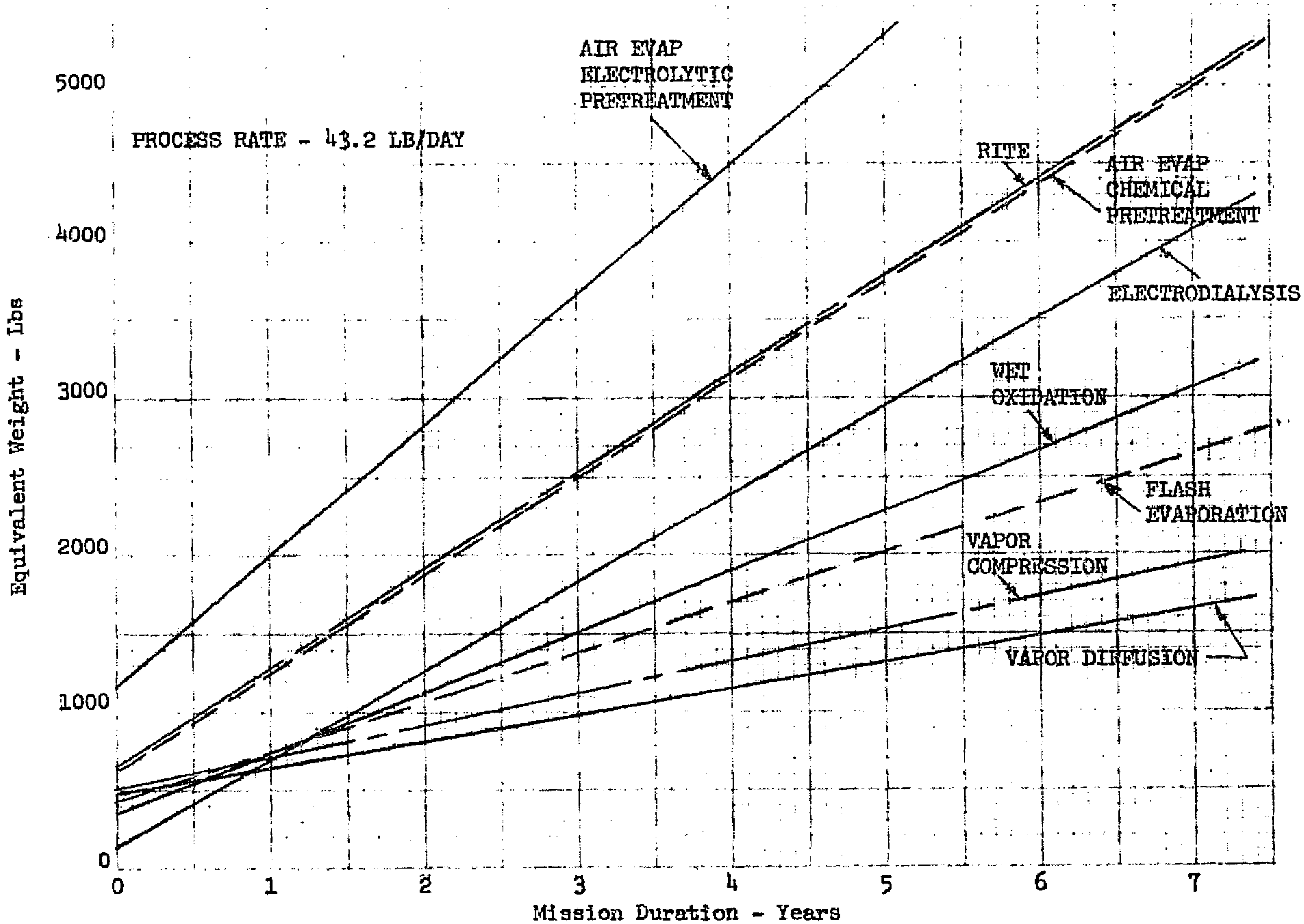

FIGURE 3-5 URINE WATER RECOVERY WEIGHT TRADE - LUNAR BASE

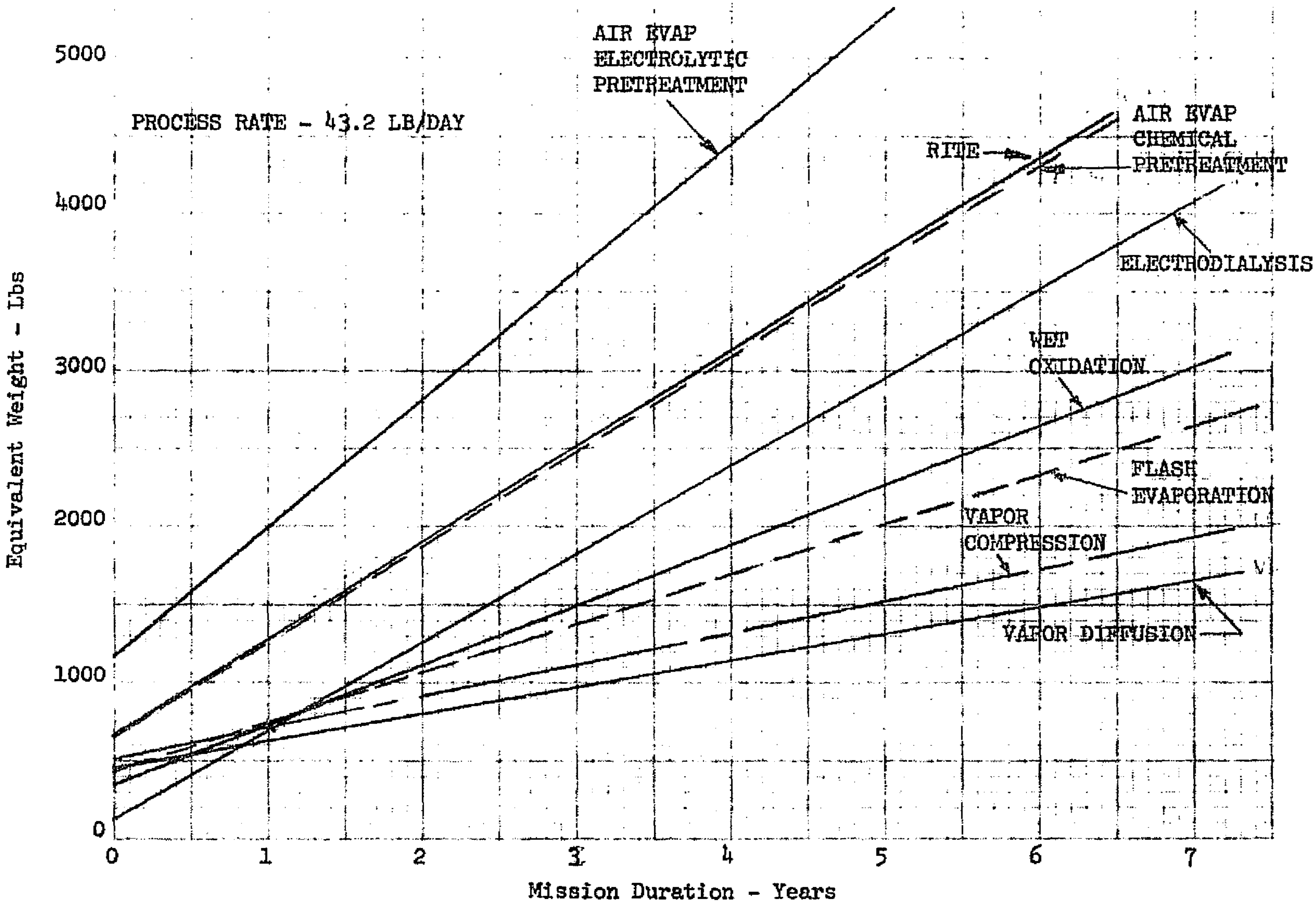

FIGURE 3-6 URINE RECOVERY WEIGHT TRADE - INTERPLANETARY

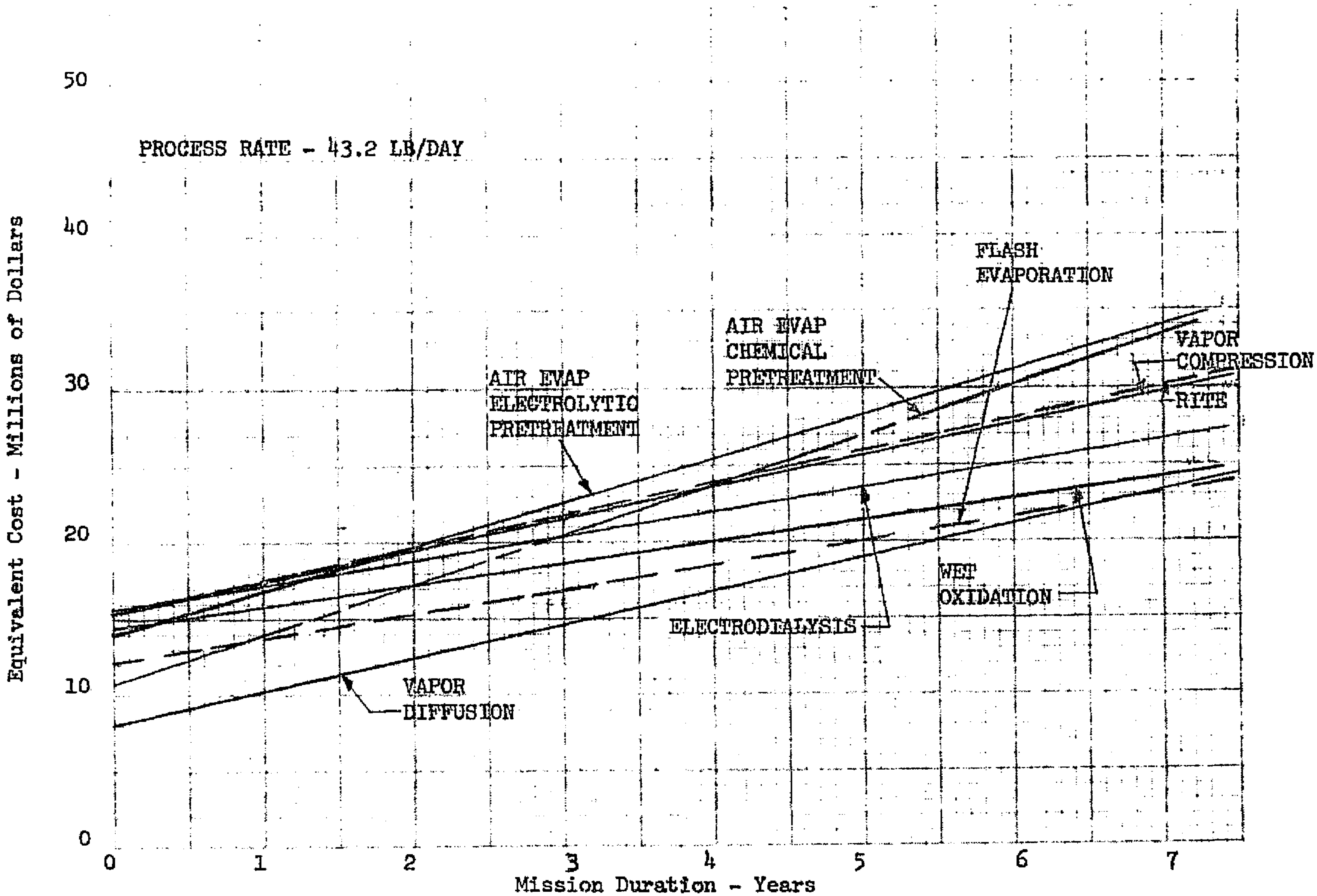

FIGURE 3-7 URINE WATER RECOVERY COST TRADE - SPACE STATION

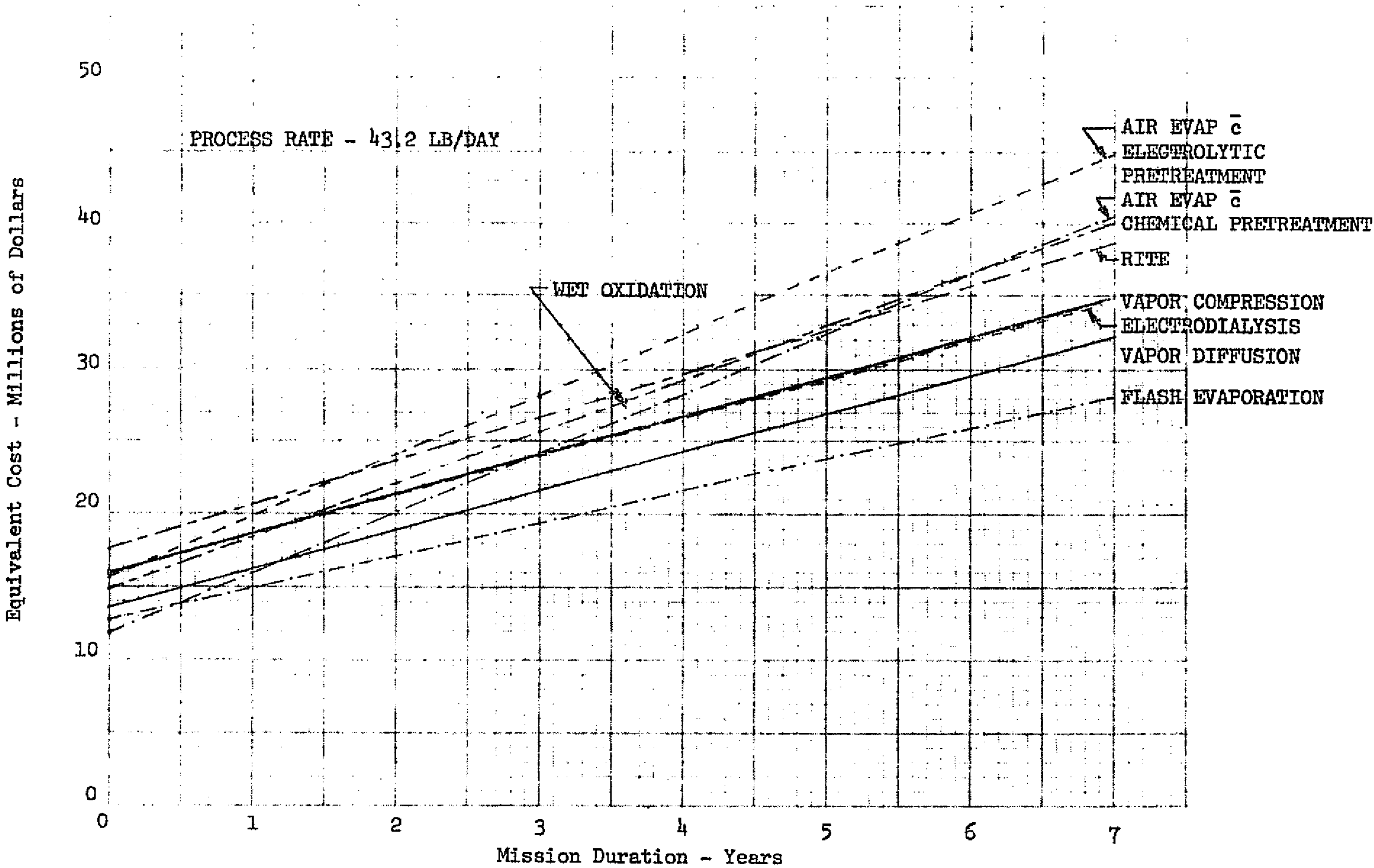

FIGURE 3-8 URINE WATER RECOVERY COST TRADE - LUNAR BASE

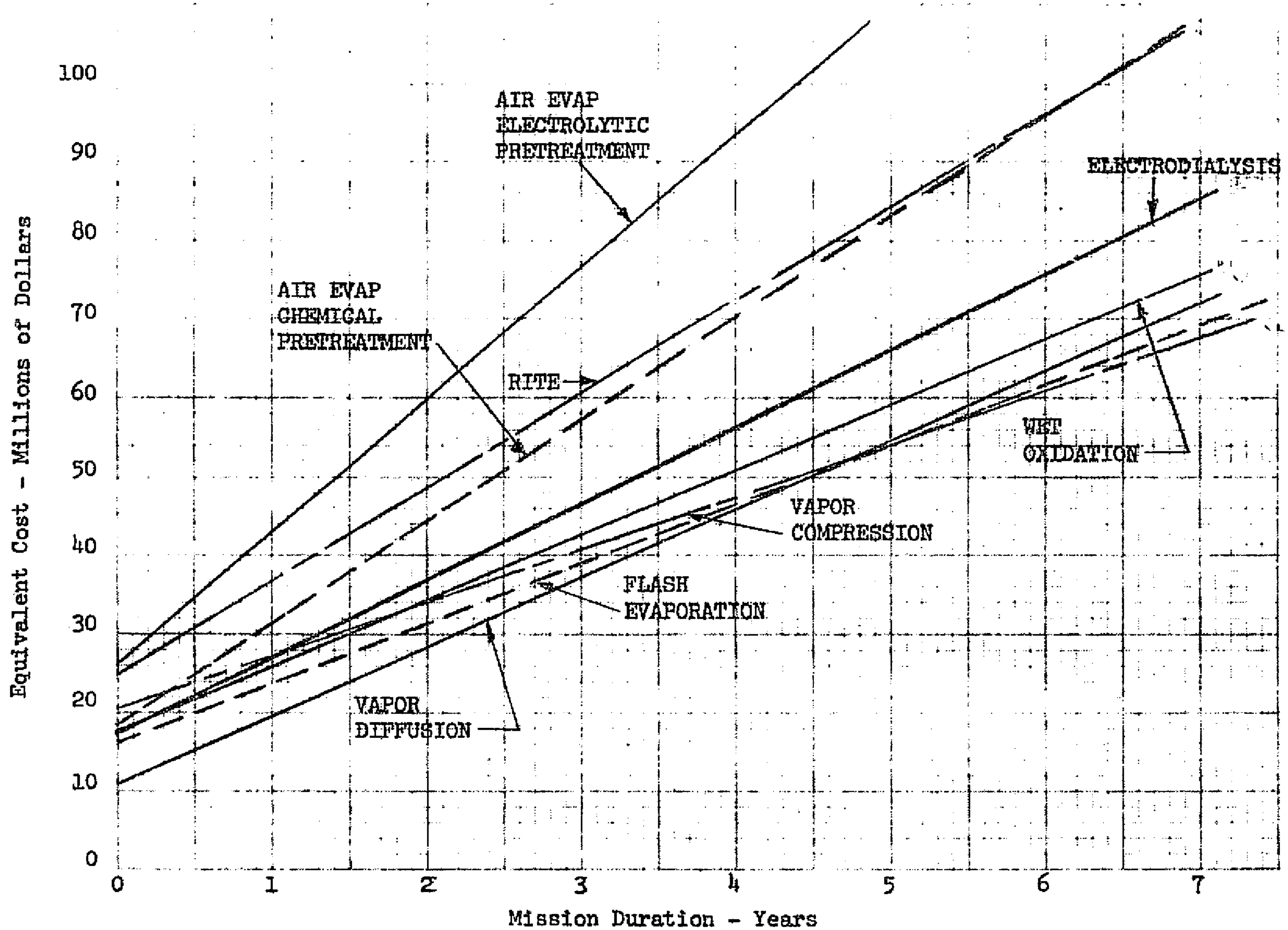

FIGURE 3-9 URINE WATER RECOVERY COST TRADE - INTERPLANETARY

The weight tradeoff for wash water recovery is shown in Figure 3-10. Multifiltration has a significant equivalent weight advantage over reverse osmosis. Effects of the penalty differences for the different applications are small and do not show up in the figure.

Multifiltration is also favored from a cost standpoint for all applications as seen in Figure 3-11.

Consideration was also given to a single concept to process all water, urine, wash condensate and experiment water. The concepts which can potentially perform these functions are traded in Figures 3-12 to 3-17. Vapor compression and flash evaporation trade favorably from a weight standpoint as seen in Figures 3-12 to 3-14. Cost advantages are shown for vapor compression, electrodialysis, and flash evaporation for the Space Station and flash evaporation and vapor compression for Lunar Base. Interplanetary application indicates cost advantages for vapor compression, wet oxidation, and flash evaporation.

Figures 3-18 to 3-20 show the equivalent weight tradeoffs for the 4 candidate waste management concepts. The vacuum dry with flush and the slinger-vacuum drying concepts are about equal in equivalent weight and they are favored over the other candidates. This is due mainly to the lower expendable requirements of the favored concepts.

Figures 3-21 to 3-23 give the equivalent cost trades for waste management concepts.

The slinger-vacuum drying concept is lowest cost for all three applications by from 3 to 4 million dollars. This is due to the lower recurring cost of the concept. The Bag/Storage and the Bag/Vacuum drying concepts became less competitive for the interplanetary mission because of the higher resupply cost.

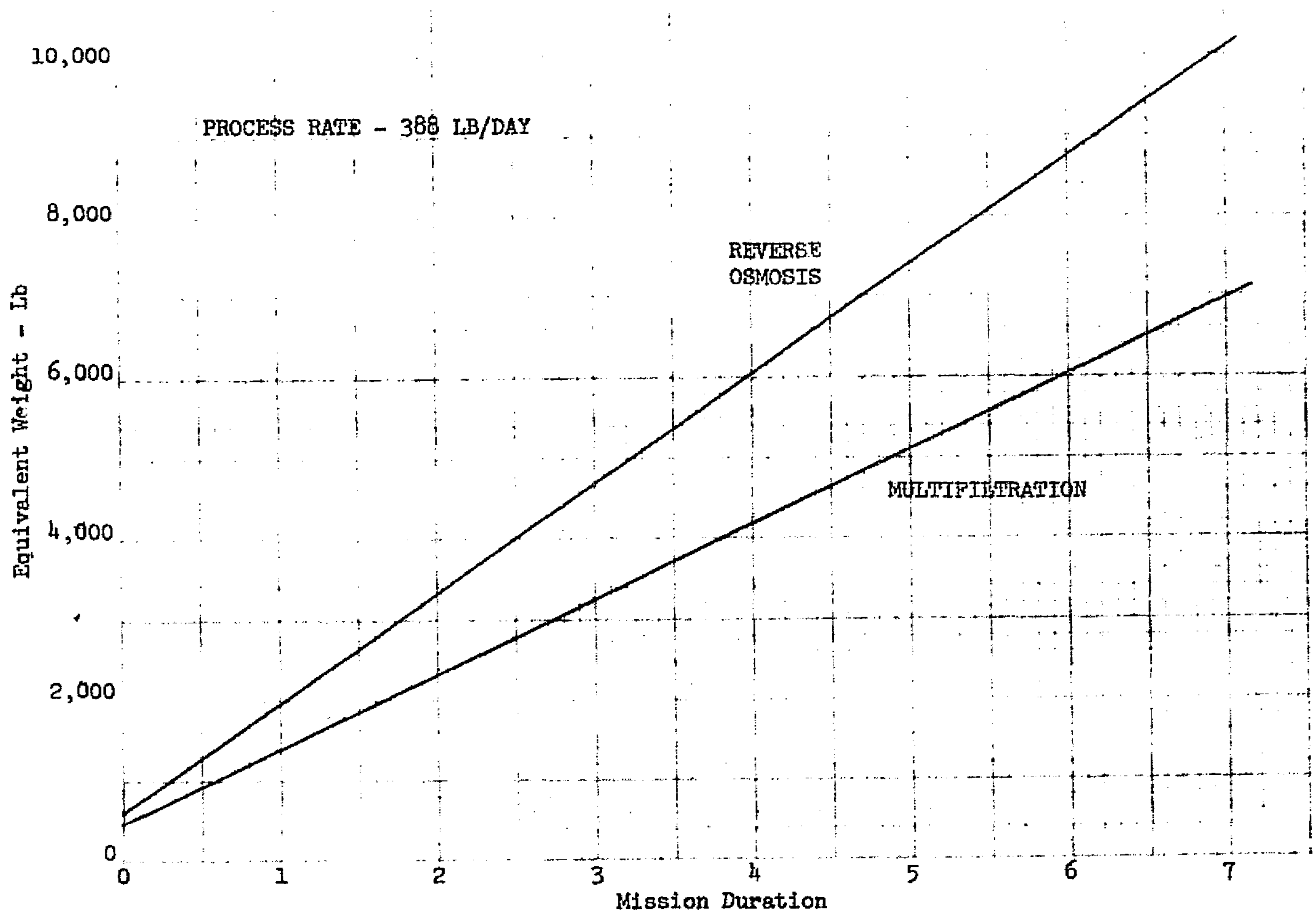

FIGURE 3-10 WASH WATER RECOVERY WEIGHT TRADE

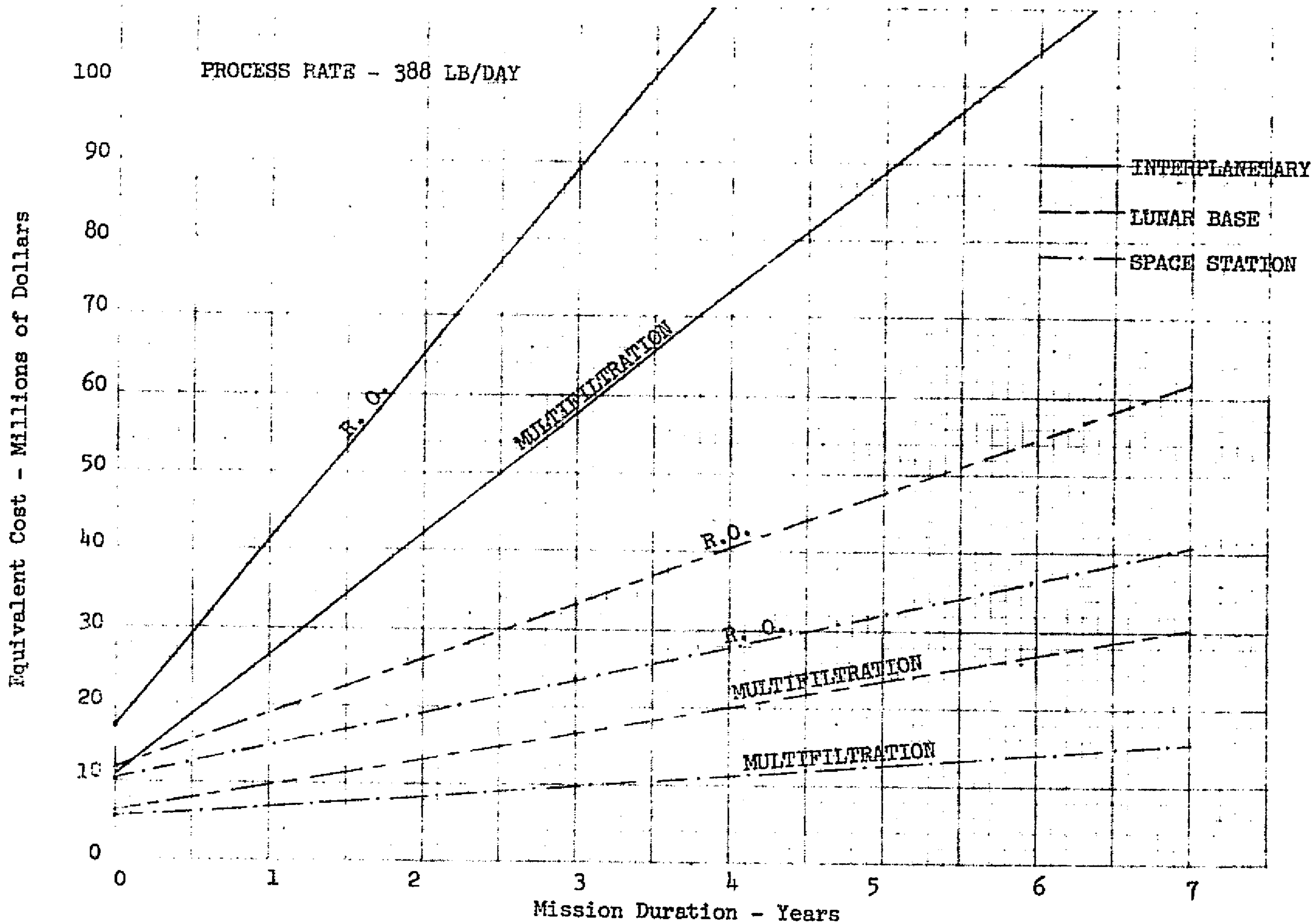

FIGURE 3-11 WASH WATER RECOVERY COST TRADE

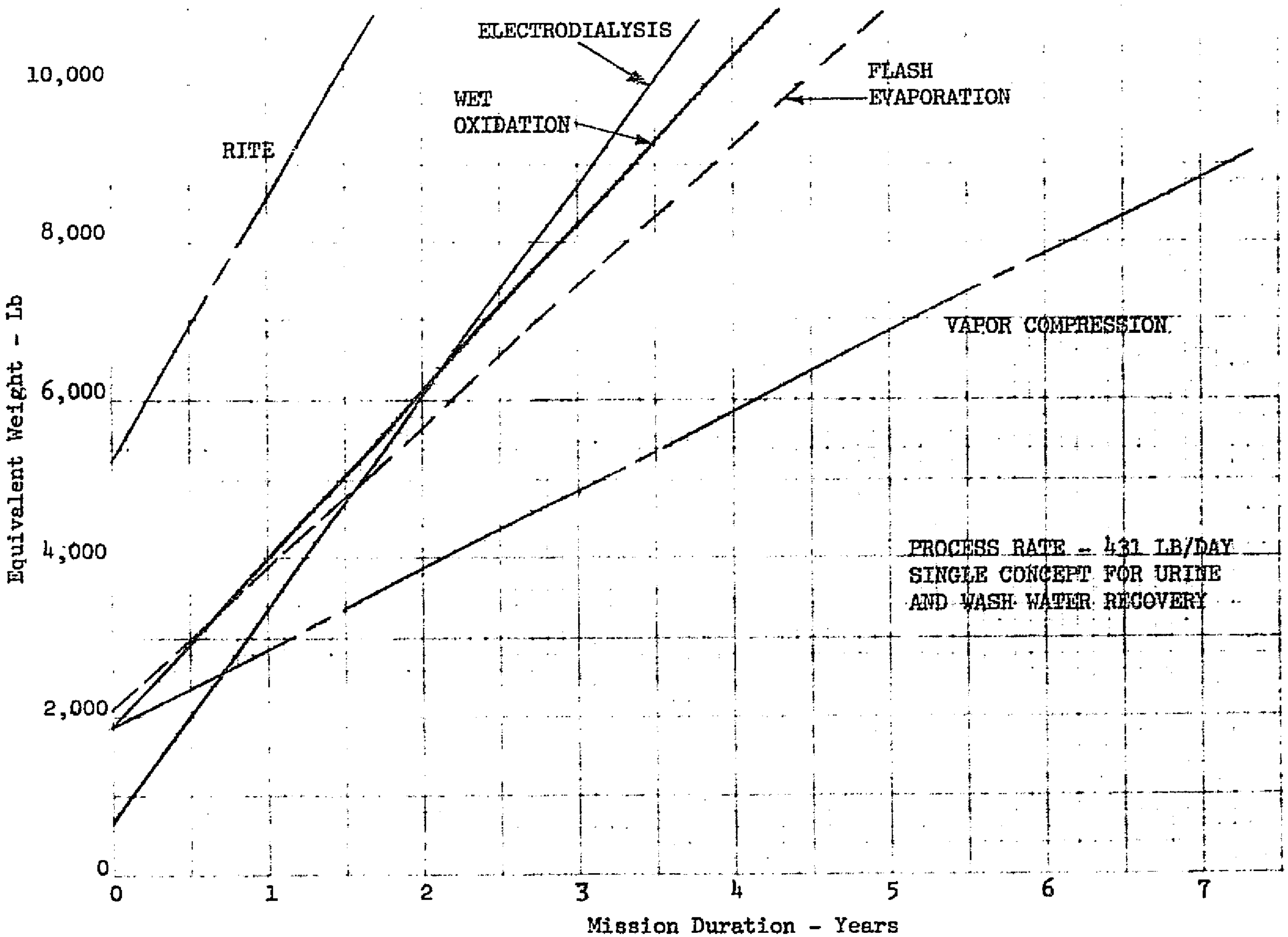

FIGURE 3-12 URINE AND WASH WATER RECOVERY WEIGHT TRADE - SPACE STATION

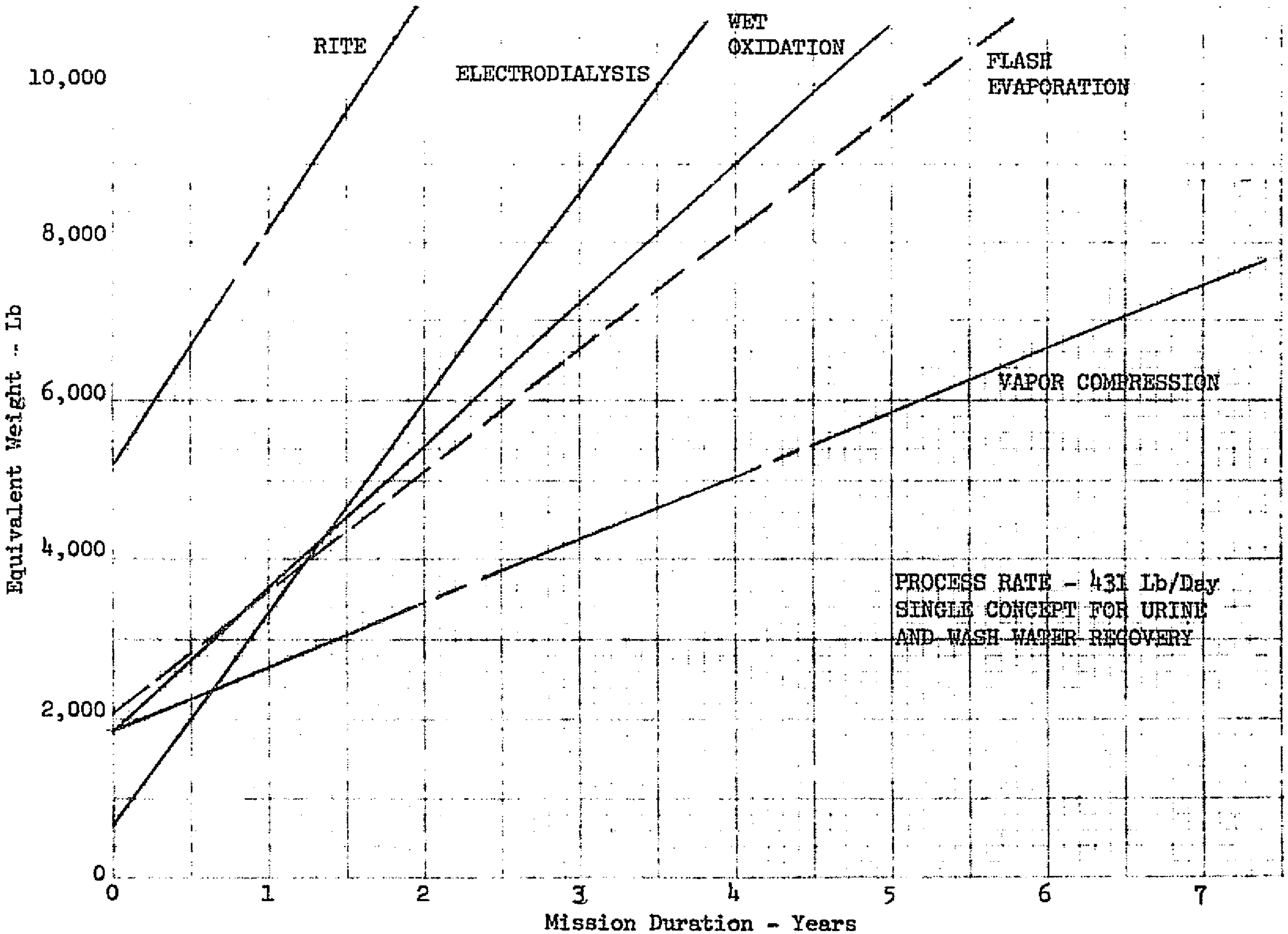

FIGURE 3-13 URINE AND WASH WATER RECOVERY WEIGHT TRADE - LUNAR BASE

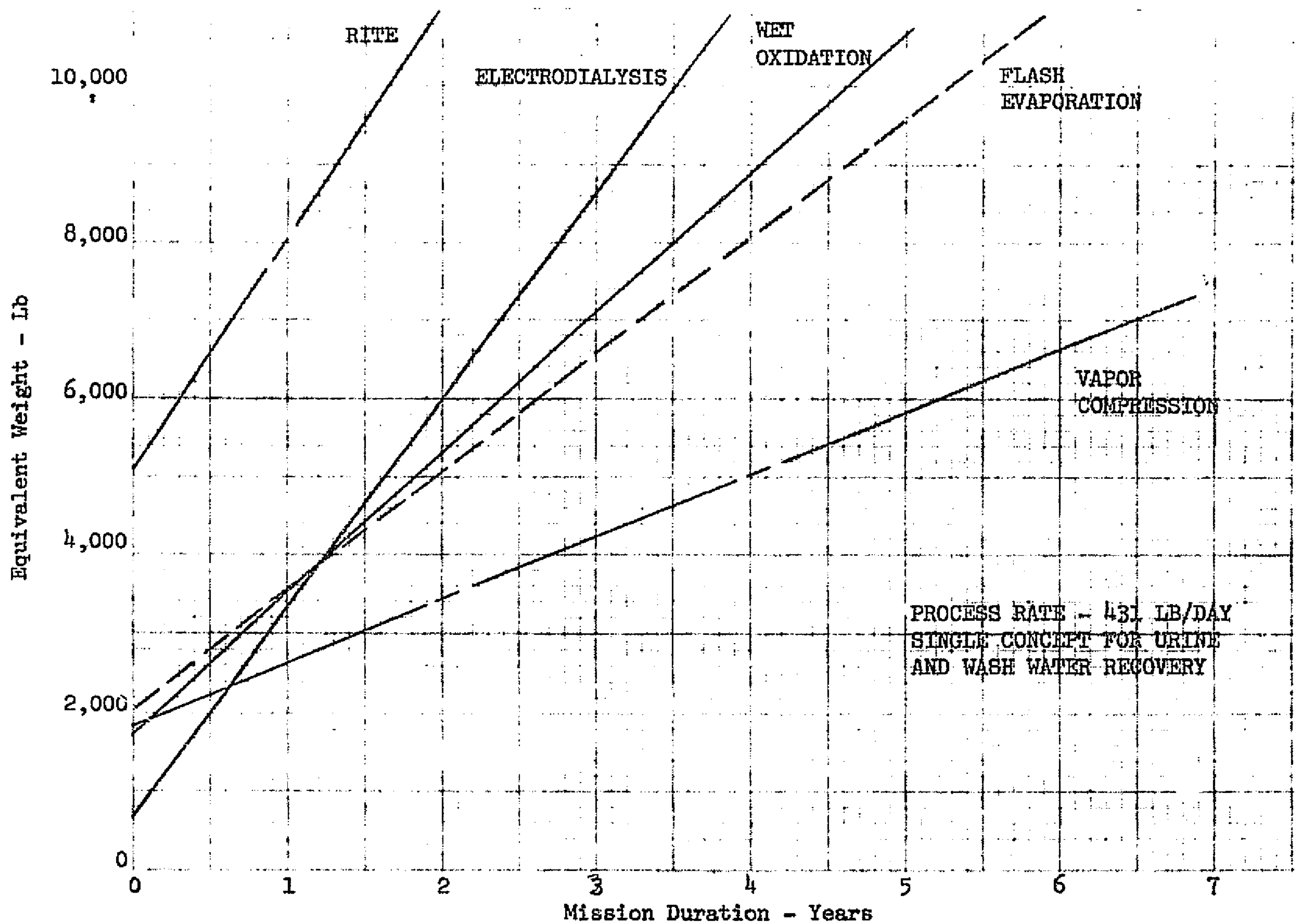

FIGURE 3-14 URINE AND WASH WATER RECOVERY WEIGHT TRADE - INTERPLANETARY

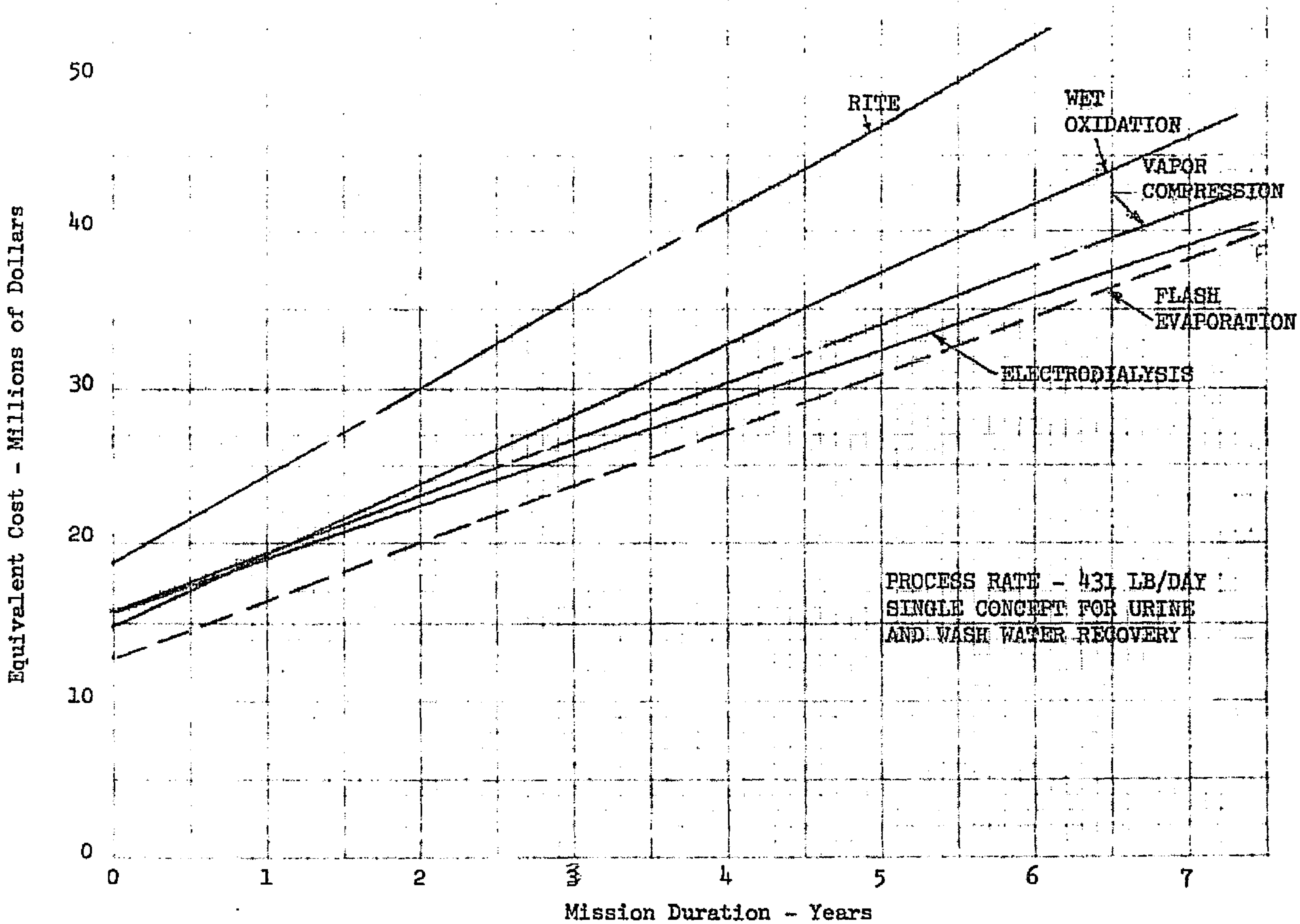

FIGURE 3-15 URINE AND WASH WATER RECOVERY COST TRADE - SPACE STATION

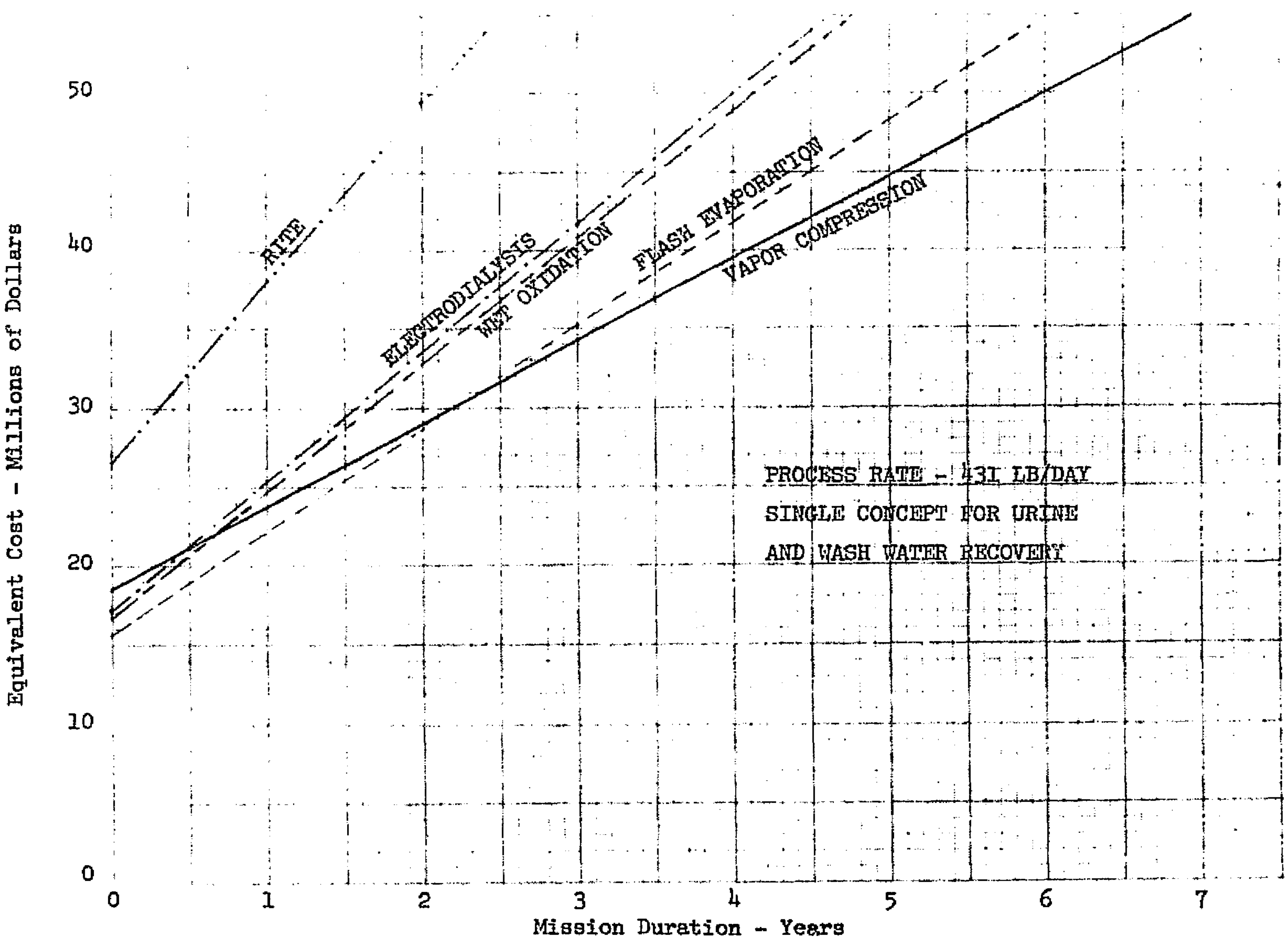

FIGURE 3-16 URINE AND WASH WATER RECOVERY COST TRADE - LUNAR BASE

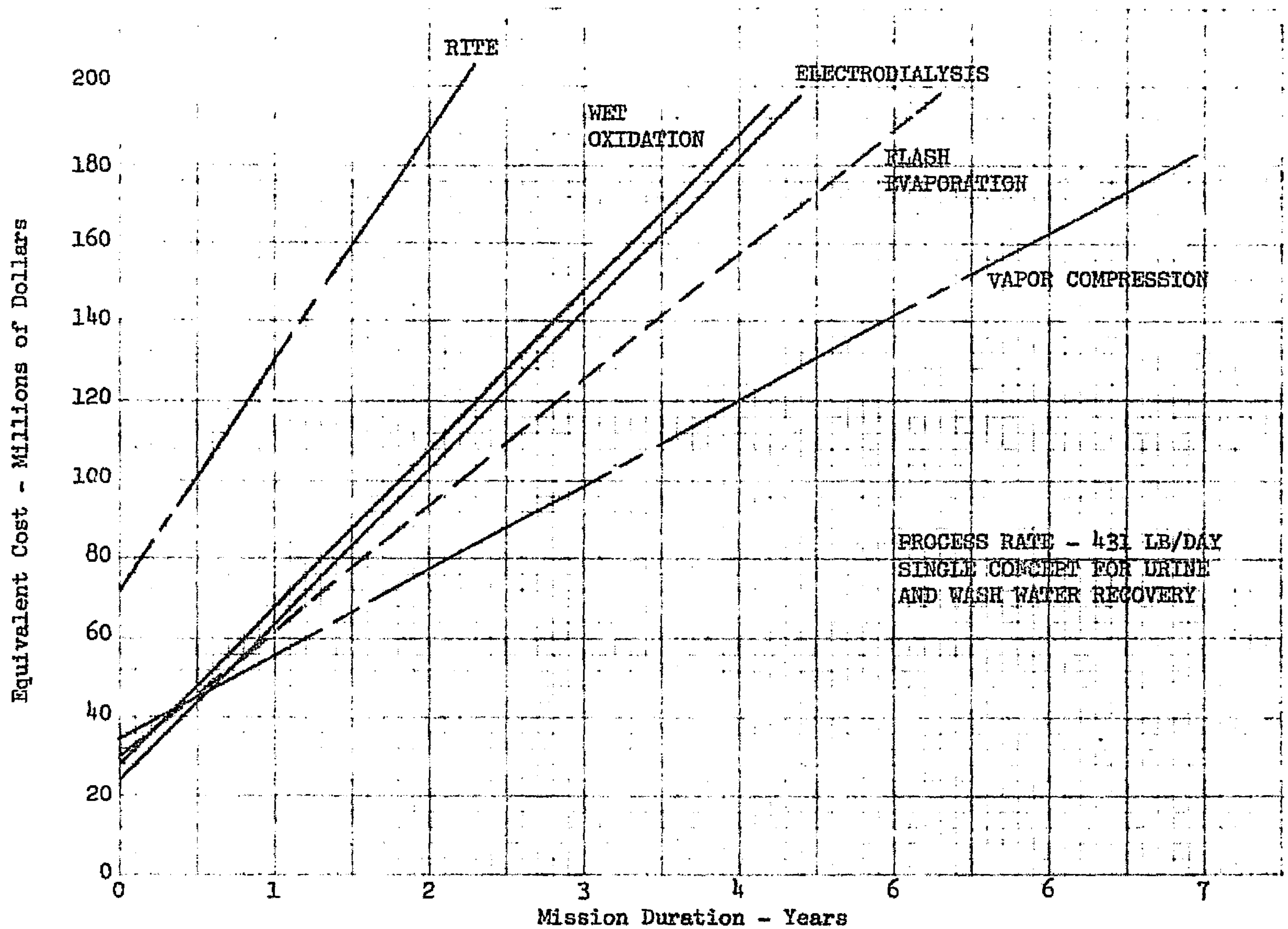

FIGURE 3-17 URINE AND WASH WATER RECOVERY COST TRADE - INTERPLANETARY

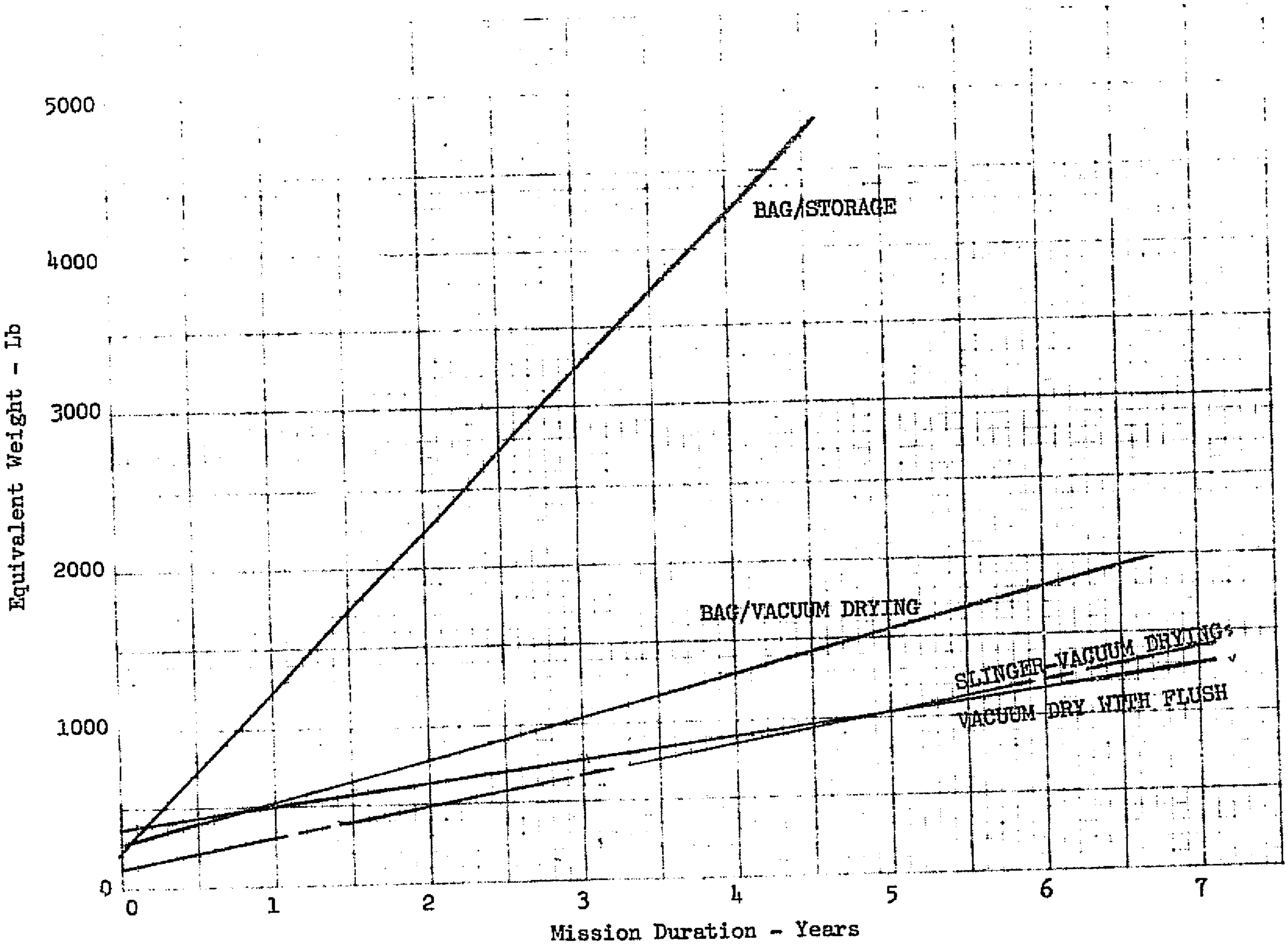

FIGURE 3-18 WASTE MANAGEMENT WEIGHT TRADEOFF - SPACE STATION

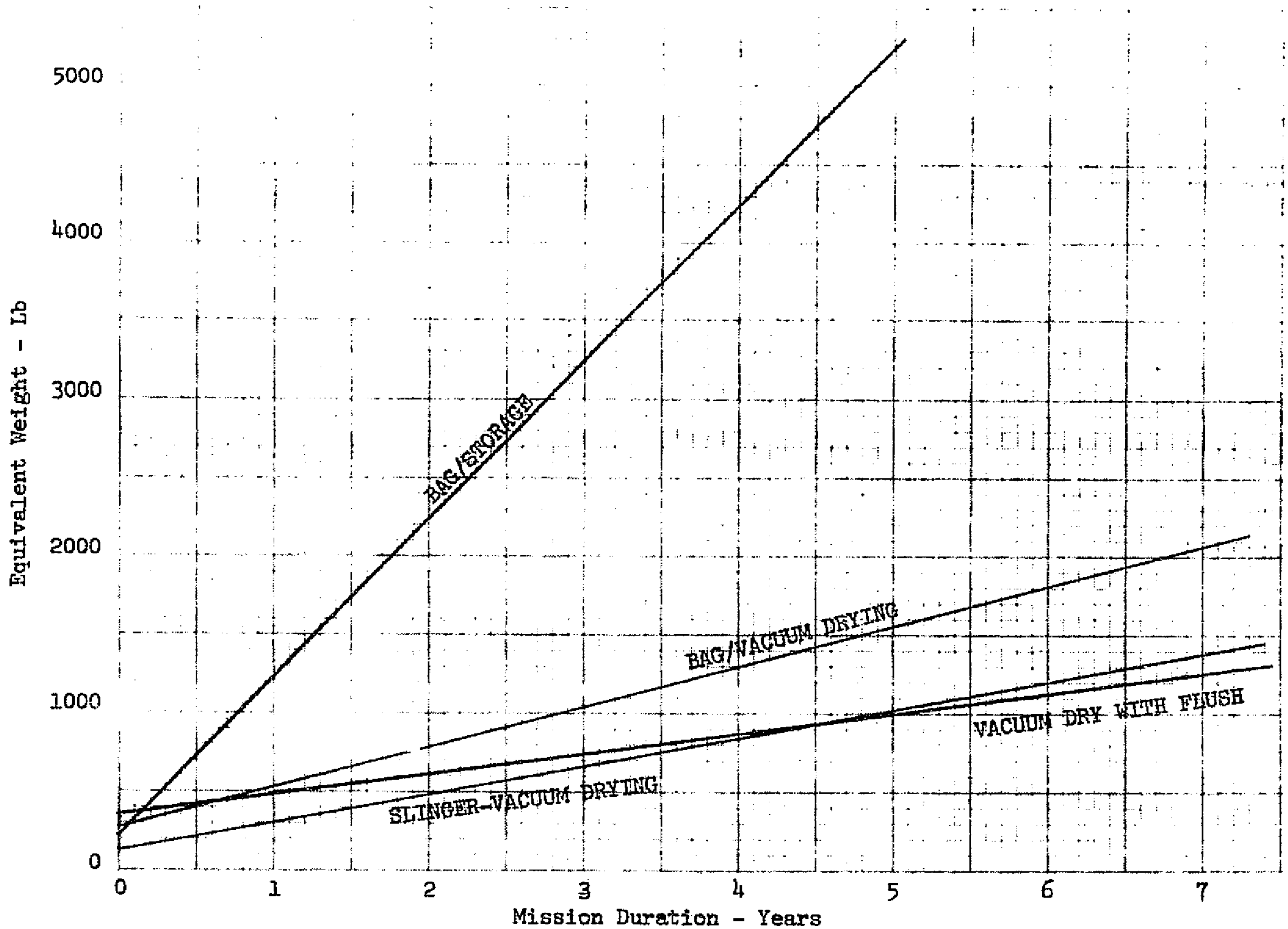

FIGURE 3-19 WASTE MANAGEMENT WEIGHT TRADEOFF - LUNAR BASE

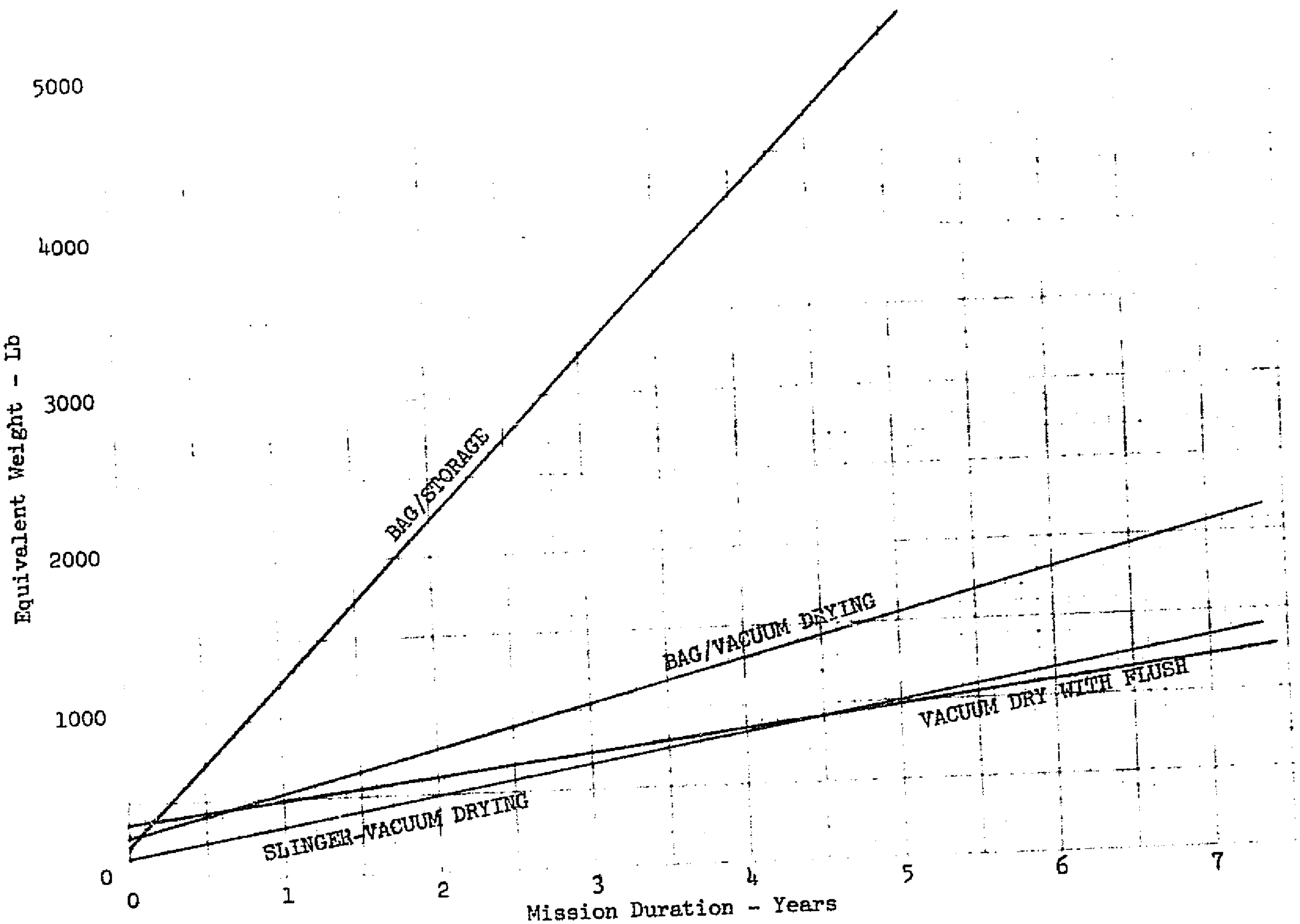

FIGURE 3-20. WASTE MANAGEMENT WEIGHT TRADEOFF - INTERPLANETARY

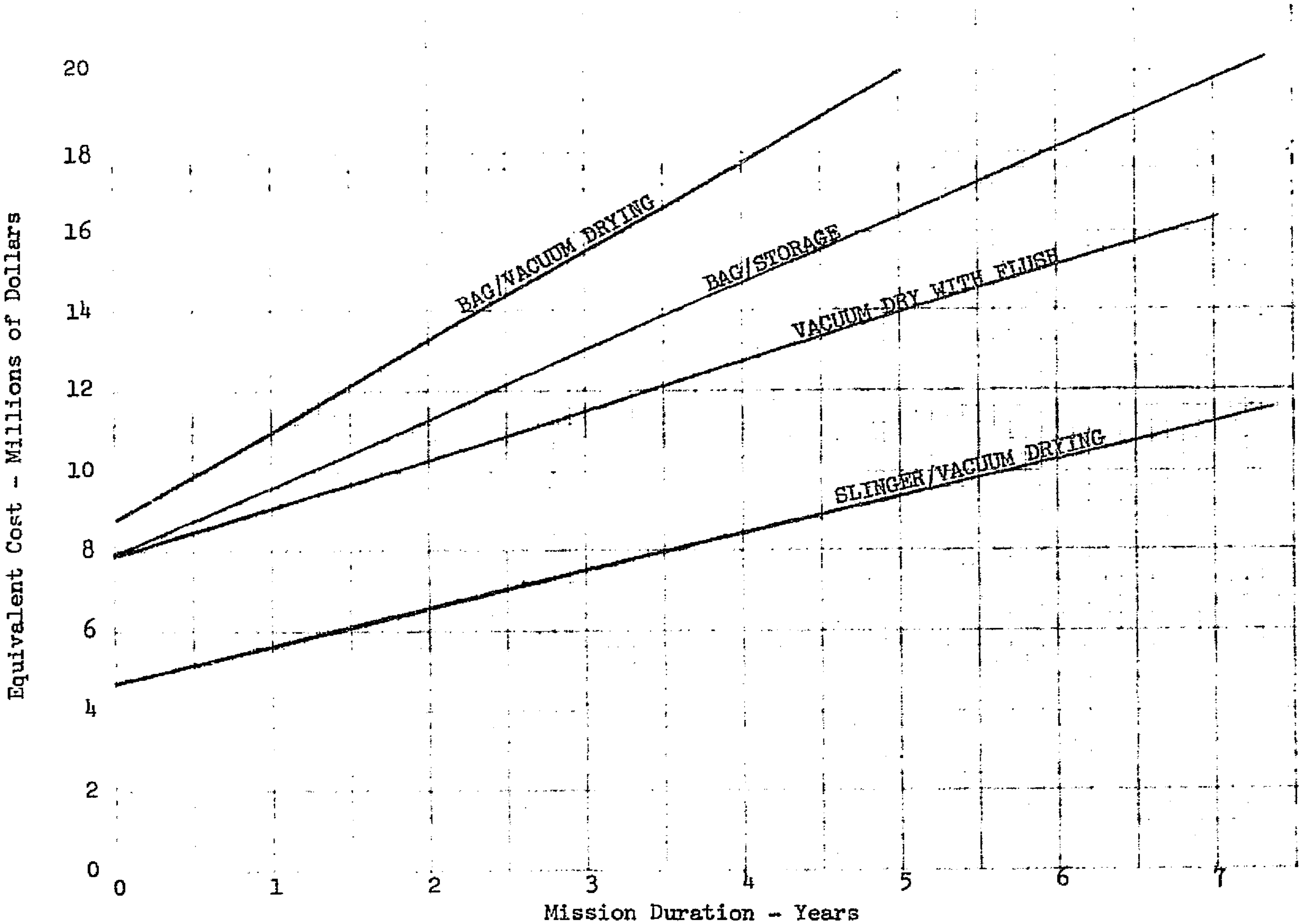

FIGURE 3-21. WASTE MANAGEMENT COST TRADEOFF - SPACE STATION

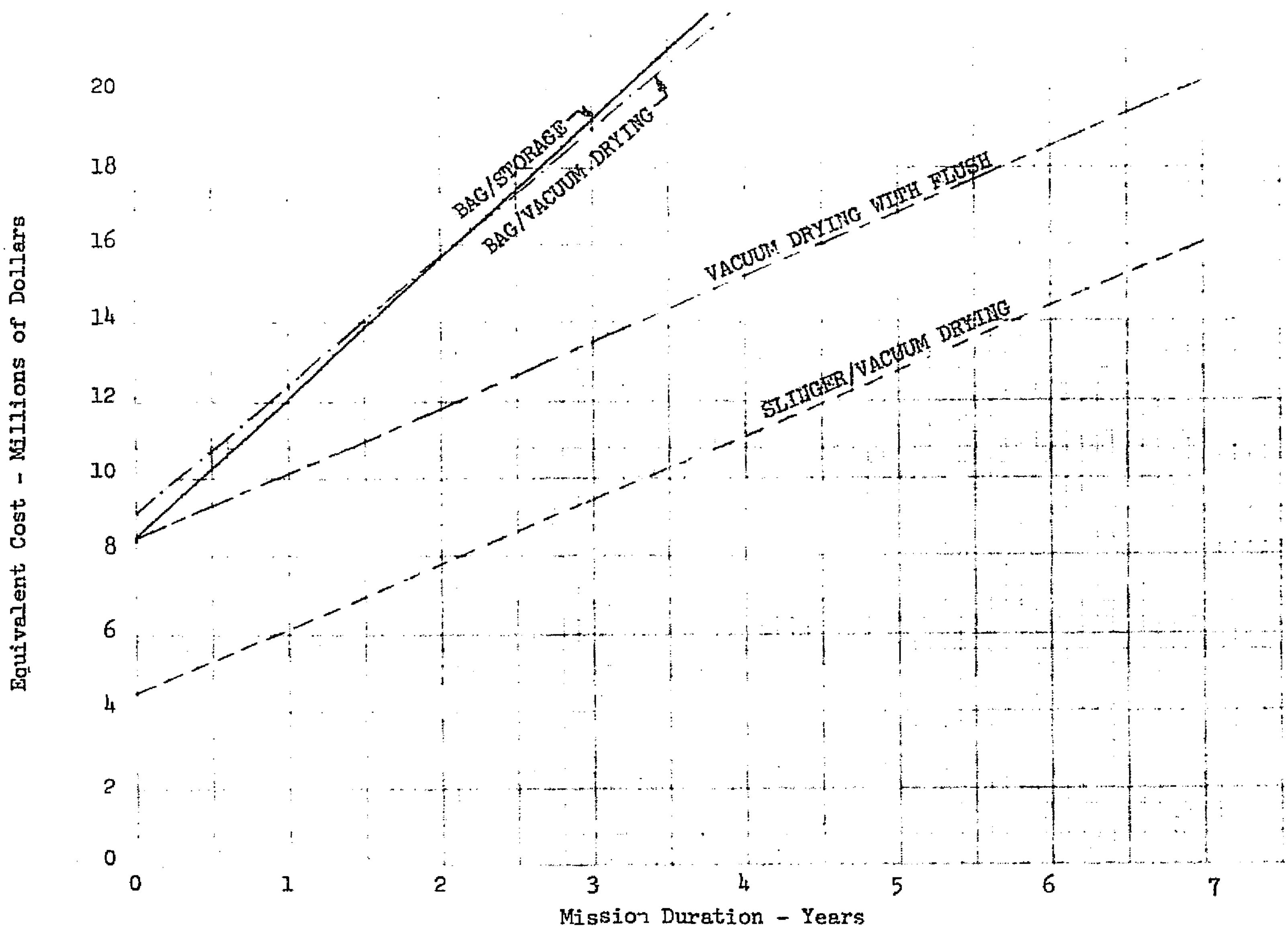

FIGURE 3-22 WASTE MANAGEMENT COST TRADEOFF - LUNAR BASE

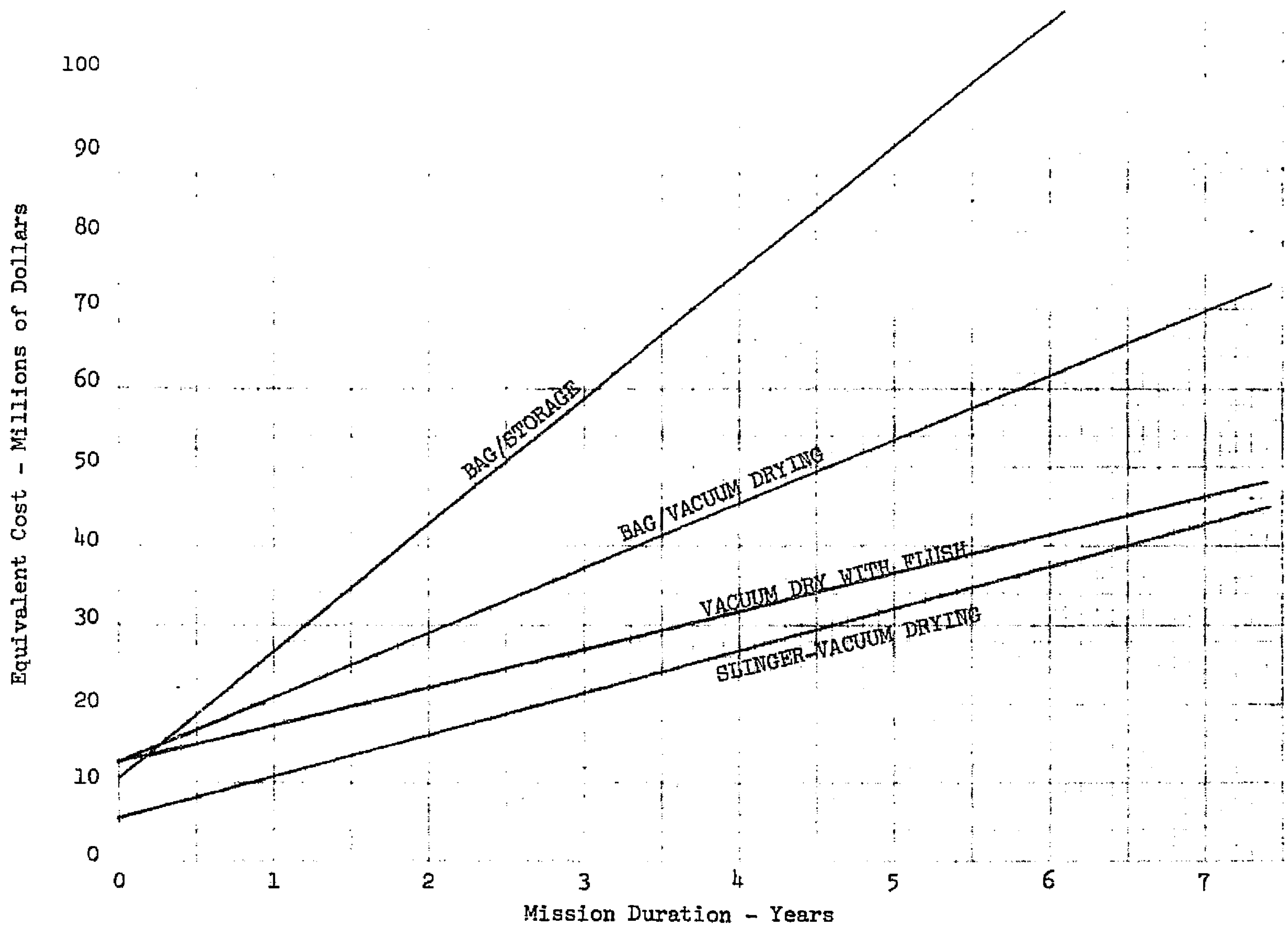

FIGURE 3-23. WASTE MANAGEMENT COST TRADE - INTERPLANETARY

In the paragraphs above some conclusions have been made regarding the equivalent weight and cost of the candidate concepts. Of equal value, but more difficult to determine with precision are the qualitative criteria. These criteria are developed and described in Section 2.3. An evaluation was made of the candidate concepts and these are shown in Table 3-4. Ratings are listed as H (high), M (medium), and L (low). From the data in the table, vapor compression is the highest rated concept for urine recovery, primarily due to its high rating in flexibility and interface insensitivity. The concept can process a variety of different types of waste water and has no cooling of heating line interfaces. The air evaporation with electrolytic pretreatment and flash evaporation tied for second position in the qualitative evaluation.

The wash water evaluation showed that multifiltration rated first with reverse osmosis a close second. Multifiltration rated high due to its high ratings in performance, safety, and development confidence.

The slinger/vacuum drying waste management concept was slightly superior to the vacuum dry with flush because of interface insensitivity, simplicity, safety, and development confidence. An important consideration not reflected in this evaluation are the aesthetic values of the vacuum dry with flush concept due to the anal wash feature.

Based on the evaluations described above, several candidate configurations were generated for each application. Generally, only the concepts which finished high in the qualitative evaluation are included. Table 3-5 lists the candidates along with their key characteristics. A code was developed to aid in identifying each candidate configuration, an example follows:

S - VC - RO - F

- F — Vacuum dry with flush for waste
- RO — Reverse osmosis for wash water processing
- VC — Vapor compression for urine processing
- S — Space Station application

TABLE 3-4

QUALITATIVE EVALUATION

WATER AND WASTE MANAGEMENT CONCEPTS

CONCEPT	PROCESS MATERIAL: URINE	FECAL WATER	WASH WATER	FECES	PERFORMANCE	SAFETY	DEVELOPMENT CONFIDENCE	FLEXIBILITY	GROWTH POTENTIAL	INTERFACE INSENSITIVITY	SIMPLICITY
Vapor Compression	X	X	X		H	H	H	H	M	H	M
Air Evaporation Electrolytic Pretreatment	X				H	H	H	M	M	L	M
Air Evaporation Chemical Pretreatment	X				M	H	H	M	M	L	M
Vapor Diffusion	X				M	H	M	M	M	M	M
Electrodialysis	X		X		L	H	L	M	H	H	M
Flash Evaporation	X		X		H	H	M	M	H	L	L
Wet Oxidation	X	X	X		M	L	L	M	H	M	L
RITE	X	X	X		M	M	M	H	H	M	L
Reverse Osmosis			X		M	M	M	H	H	H	M
Multifiltration			X		H	H	H	H	M	H	H
Bag/Storage Waste				X	L	M	H	L	L	H	H
Bag/Vacuum Drying Waste				X	M	M	H	M	M	M	M
Slinger-Vacuum Drying Waste				X	H	H	H	M	M	M	H
Vacuum Dry with Flush Water				X	H	M	M	H	H	L	M

H - HIGH RATING; M - MEDIUM RATING; L - LOW RATING

TABLE 3-5

CANDIDATE CONFIGURATIONS

FOR WATER AND WASTE MANAGEMENT

APPLICATION/RATIONALE	FUNCTION	CONCEPT
SPACE STATION*		
S-VC-RO-F Lowest Final Weight for Urine Recovery	Urine H_2O Recovery Wash H_2O Recovery Waste Management	Vapor Compression Reverse Osmosis Vacuum dry with flush
S-FE-M-S Lowest Initial Cost	Urine H_2O Recovery Wash H_2O Recovery Waste Management	Flash Evaporation Multifiltration Slinger/Vacuum Drying
S-VC-F Lowest Weight Single Concept	Urine and Wash Water Recovery Waste Management	Vapor Compression Vacuum dry with flush
S-VC-M-S Lowest Final Weight for 3 Year Mission	Urine Water Recovery Wash Water Recovery Waste Management	Vapor Compression Multifiltration Slinger/Vacuum Drying
LUNAR BASE		
L-AE-M-S Proven concepts (90 day simulator run)	Urine Water Recovery Wash Water Recovery Waste Management	Air evaporation with electrolytic pretreatments Multifiltration Slinger/Vacuum Drying
L-VD-RO-S Second lowest cost and weight for urine and wash water recovery	Urine Water Recovery Wash Water Recovery Waste Management	Vapor Diffusion Reverse Osmosis Slinger/Vacuum Drying
L-WO-F Promising single concept for weight and cost	Urine and Wash Water Recovery Waste Management	Wet Oxidation Vacuum dry with flush

* Only concepts considered which rate in the top three in the qualitative evaluation.

TABLE 3-5 (continued)

CANDIDATE CONFIGURATIONS

FOR WATER AND WASTE MANAGEMENT

APPLICATION/RATIONALE	FUNCTION	CONCEPT
L-VC-M-S Highest qualitative rating	Urine Water Recovery Wash Water Recovery Waste Management	Vapor Compression Multifiltration Slinger/Vacuum Drying
INTERPLANETARY		
I-WO-F Primising single concept for weight and cost	Urine & Wash Water Recovery Waste Management	Wet Oxidation Vacuum dry with flush
I-VD-M-S Lowest weight and cost	Urine Water Recovery Wash Water Recovery Waste Management	Vapor Diffusion Multifiltration Slinger/Vacuum Drying
I-VC-M-F Lowest weight rated in top 3 from qualitative evaluation	Urine Water Recovery Wash Water Recovery Waste Management	Vapor Compression Multifiltration Vacuum dry with flush

Configuration S-VC-RO-F represents the lowest final weight for urine water recovery concept which is qualitatively acceptable. Reverse osmosis and vacuum dry with flush concepts were included to produce the SSP design. S-FE-M-S represents the lowest initial cost concept for all functions. S-VC-F is based on the lowest weight single concept and the waste management concept with flush was included since this combination has received development effort in the past. S-VC-M-S is also included because it has the lowest final weight for a 3 year mission.

Since Lunar Base programs are likely to be further in the future than Space Station programs, more advanced concepts were considered along with several well-proven configurations. Weight penalties are quite similar between Lunar Base and Space Station, however, cost penalties are higher for the lunar base.

Configuration L-AE-M-S was chosen because it is a proven concept, it is essentially the configuration used in the 90 day MDAC Space Station Simulator. The concept L-VD-RO-S rated well regarding equivalent weight and cost for urine and wash water recovery, although it ranked poorly in qualitative criteria. Configuration L-WO-F was chosen because wet oxidation also shows great promise and has the advantage of processing nearly all types of wastes and trash. Vacuum dry with flush was selected with the wet oxidation because the wet oxidation process can process this product water. Configuration S-VC-M-S was included because it ranked highest from a qualitative standpoint.

The concepts for Interplanetary include two configurations considered future development concepts and one proven concept. I-WO-F is identical to configuration L-WO-F and was chosen because of its capability of handling a wide variety of wastes. This can be important on a long duration flight where waste storage volume is critical. I-VD-M-S was chosen because the urine recovery concept, the wash recovery concept and the slinger/vacuum dry waste management concept will represent the lowest equivalent weight and cost for interplanetary application. I-VC-M-F was chosen because it represents well proven concepts and will serve as a datum for the other two more advanced configurations chosen for Interplanetary application.

Section 4

CONFIGURATION EVALUATION

The candidate configurations developed in Section 3.5 are evaluated in this section. The procedure followed is to perform equivalent weight and cost comparisons and to evaluate the configurations based on qualitative criteria. An additional important parameter was added in the configuration evaluation, i.e., penalties for makeup water. Based on the mass balance calculations described in Section 3.3, makeup water requirements were calculated for each candidate configuration. The result is shown in Table 4-1. It can be seen that excess water is available in some configurations but others with lower efficiences require substantial amounts of makeup water. The equivalent weight and cost penalties for the makeup water is included in the comparisons. Credit was not given to the configurations with excess water since not enough is known about the missions to know if this water can be used or not, say for experiments or cooling. However, no penalty was assessed for storage or overboard expulsion of this water.

4.1 Quantitative Evaluations

Weight tradeoffs are shown in Figures 4-1 to 4-3. Configuration S-VC-M-S was lowest weight for a 3 year Space Station mission due to low initial weight and no makeup water requirement. The relatively high recovery efficiency, 98.5% of the multifiltration concept and 96.9% for vapor compression results in excess water. The wash water unit processes about 9 times more water and therefore its efficiency has a much larger influence on makeup water requirements. Weights of the individual elements of the configurations can be seen in Table 4-2.

Results shown in Figure 4-2 for Lunar Base are similar to the results shown for Space Station. Configuration L-VC-M-S shows the lowest weight [illegible] the entire mission. This again is because the concept employing multi-filtration had no makeup water requirement and hence a much lower overall equivalent weight.

TABLE 4-1

WATER BALANCE FOR
CANDIDATE CONFIGURATIONS

Configuration	3 Yr Excess (lb)	3 Yr Makeup Requirement (Lb)
SPACE STATION		
S-VC-RO-F		5,245
S-FE-M-S	394	
S-VC-F		4,826
S-VC-M-S	1280	
LUNAR BASE		
L-AE-M-S	394	
L-VD-RO-S		6,558
L-WO-F		14,099
L-VC-M-S	1280	
INTERPLANETARY		
I-WO-F		14,099
I-VD-M-S	860	
I-VC-M-F	1,873	

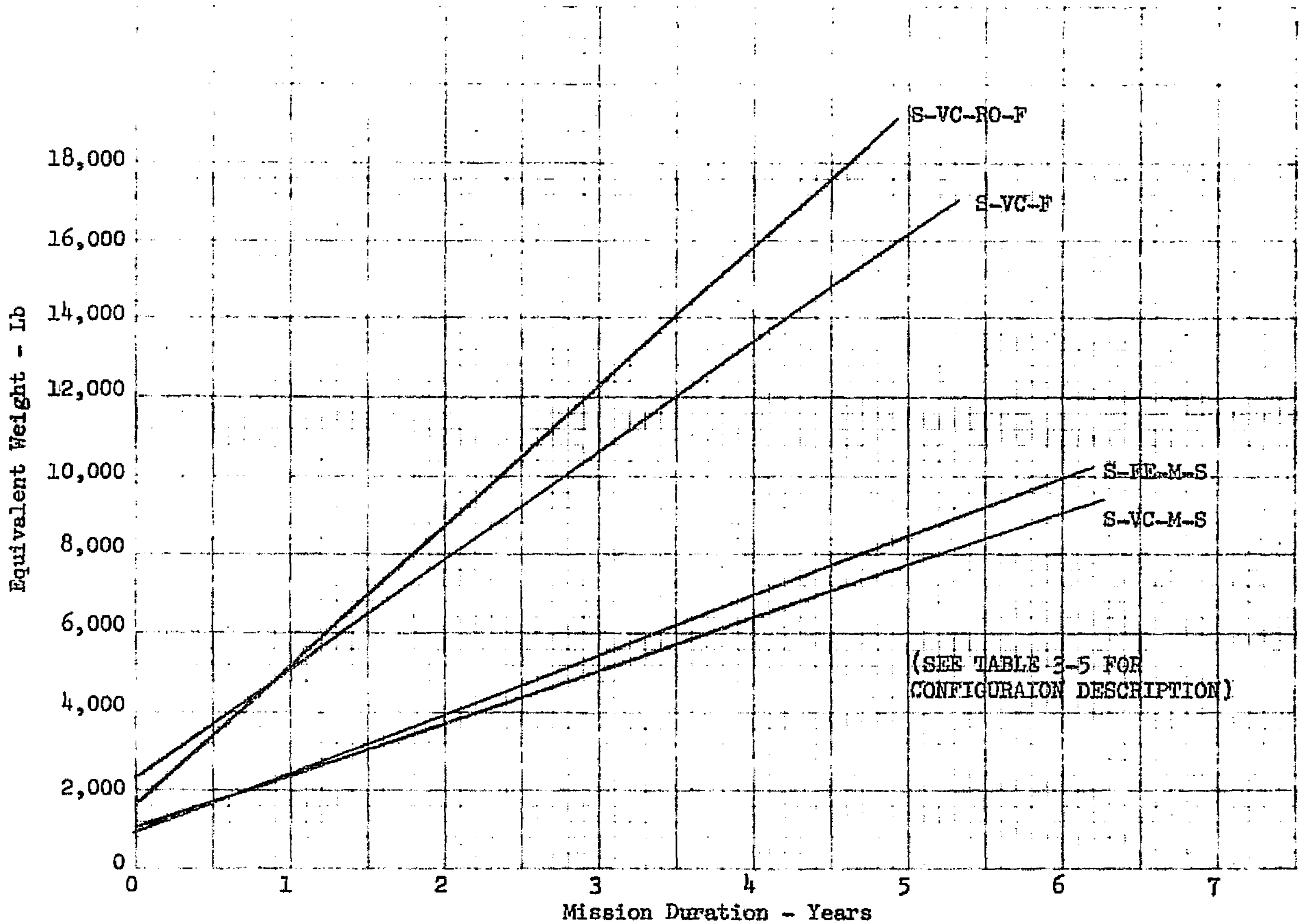

FIGURE 4-1. WEIGHT TRADEOFF OF CANDIDATE CONFIGURATIONS - SPACE STATION

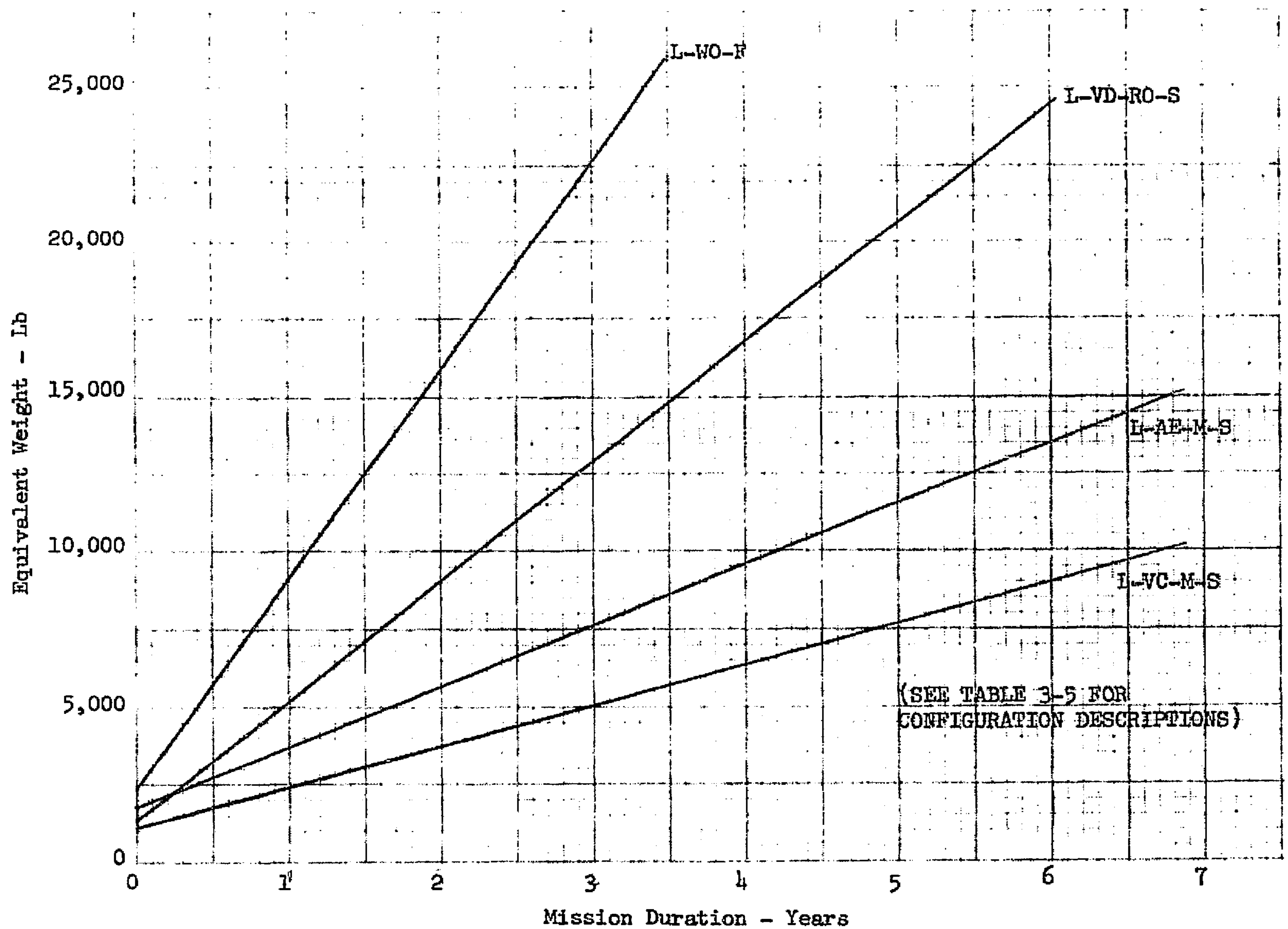

FIGURE 4-2. WEIGHT TRADEOFF FOR CANDIDATE CONFIGURATIONS - LUNAR BASE

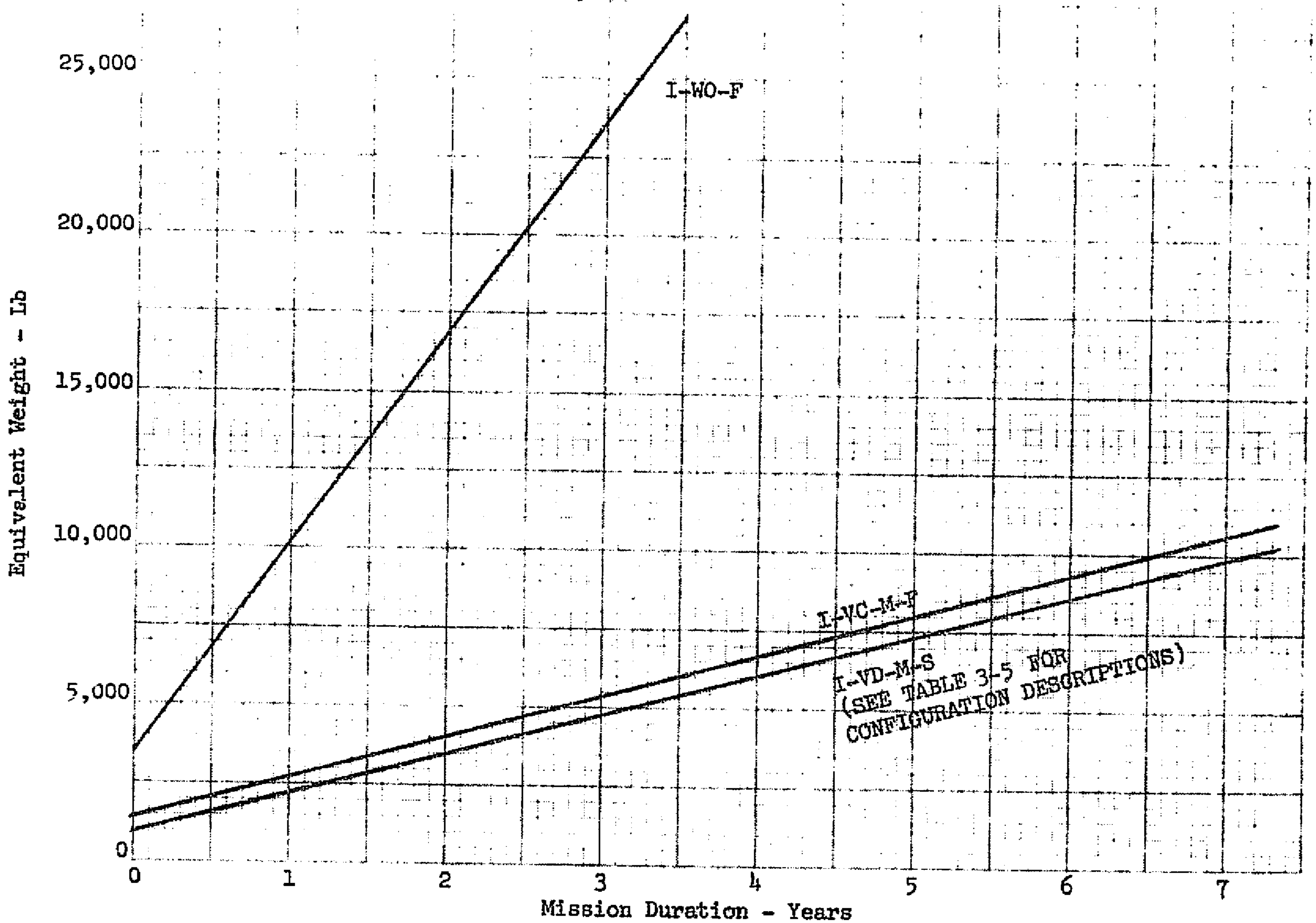

FIGURE 4-3 WEIGHT TRADEOFF FOR CANDIDATE CONFIGURATIONS - INTERPLANETARY

TABLE 4-2

WEIGHT SUMMARY FOR CANDIDATE CONFIGURATIONS

APPLICATION/FUNCTION		ITEM		Equivalent Weight (Lb) Initial	3 Year Total
SPACE STATION					
S-VC-RO-F	Urine water recovery	Vapor compression		632	1493
	Wash water recovery	Reverse osmosis		609	4698
	Waste management	Vacuum dry with flush		378	779
	Makeup water	Bladdered tanks		88	5333
			TOTAL	1707	12303
S-FE-M-S	Urine water recovery	Flash evaporation		432	1551
	Wash water recovery	Multifiltration		431	3264
	Waste management	Slinger vacuum dry		116	678
	Makeup water	Bladdered tanks		0	0
			TOTAL	979	5493
S-VC-F	Urine and wash water recovery	Vapor compression		1935	4992
	Waste management	Vacuum dry with flush		378	779
	Makeup water	Bladdered tanks		80	4906
			TOTAL	2393	10677
S-VC-M-S	Urine water recovery	Vapor compression		513	1178
	Wash water recovery	Multifiltration		431	3264
	Waste management	Slinger vacuum dry		116	678
	Makeup water	Bladdered tanks		0	0
				1060	5120

TABLE 4-2 (continued)

WEIGHT SUMMARY FOR CANDIDATE CONFIGURATIONS

APPLICATION/FUNCTION		ITEM		Equivalent Weight (Lb) Initial	Equivalent Weight (Lb) 3 Year Total
LUNAR BASE					
L-AE-M-S	Urine water recovery	Air evaporation with electrolytic pretreatment		1187	3642
	Wash water recovery	Multifiltration		430	3239
	Waste management	Slinger/vacuum dry		115	665
	Makeup water	Bladdered tanks		0	0
			TOTAL	1732	7546
L-VD-RO-S	Urine water recovery	Vapor diffusion		482	990
	Wash water recovery	Reverse osmosis		605	4624
	Waste management	Slinger/vacuum drying		115	665
	Makeup water	Bladdered tanks		112	6670
			TOTAL	1314	12949
L-WO-F	Urine and wash water recovery	Wet oxidation		1882	7537
	Waste management	Vacuum dry with flush		376	733
	Makeup water	Bladdered tanks		236	14335
			TOTAL	2494	22605
L-VC-M-S	Urine water recovery	Vapor compression		510	1118
	Wash water recovery	Multifiltration		430	3239
	Waste management	Slinger vacuum dry		115	665
	Makeup water	Bladdered tanks		0	0
				1055	5022

TABLE 4-2 (continued)

WEIGHT SUMMARY FOR CANDIDATE CONFIGURATIONS

APPLICATION/FUNCTION		ITEM		Equivalent Weight (Lb) Initial	Equivalent Weight (Lb) 3 Year Total
INTERPLANETARY					
I-WO-F	Urine and wash water recovery	Wet oxidation		1802	7414
	Waste management	Vacuum dry with flush		374	730
	Makeup water	Bladdered tanks		1408	15507
			TOTAL	3584	23651
I-VD-M-S	Urine water recovery	Vapor diffusion		468	970
	Wash water recovery	Multifiltration		430	3239
	Waste management	Slinger/vacuum drying		115	665
	Makeup water	Bladdered tanks		0	0
			TOTAL	1013	4874
I-VC-M-F	Urine water recovery	Vapor compression		626	1402
	Wash water recovery	Multifiltration		430	3239
	Waste management	Vacuum dry with flush		374	730
	Makeup water	Bladdered tanks		0	0
			TOTAL	1430	5371

Figure 4-3, depicting interplanetary configurations, shows that the concepts employing the highly efficient multifiltration have the lowest equivalent weight. Configurations I-VD-M-S and I-VC-M-S have low weights because no water makeup was required and because vapor diffusion and vapor compression are low weight concepts.

Figures 4-4 to 4-6 show the results of the cost trades for the three applications considered. The low cost configurations were the ones which included multifiltration for wash water recovery because it normally eliminated the need for resupply water and because it cost less. Multifiltration cost about 5 million dollars less initially and cost about 15 million dollars less over the three year period. Also the slinger/vacuum drying waste management concept cost about 4 million dollars less for all applications. Configuration S-FE-M-S costs about 3 to 5 million dollars less than S-VC-M-S because of the difference in cost of the urine processing concept for Space Station. The configuration using vapor compression had a lower cost for Lunar Base because its higher initial cost was offset by lower resupply costs.

The interplanetary configuration employing wet oxidation trades unfavorably because of the large makeup water requirements. The difference in costs then between the low cost configurations, I-VD-M-S and I-VC-M-F, are due to the higher costs of vapor compression for urine water recovery and vacuum dry with flush for waste management.

The above discussions indicate the results to be very dependent upon the costs of the concepts for performing the waste and the water management functions. A close examination of the data shows that the hardware costs for Space Station account for 70 to 90% of the total cost. At the other extreme, interplanetary application costs are not as strong a function of hardware costs because of the higher launch and power penalties. About 20 to 50% of interplanetary costs are due to hardware costs.

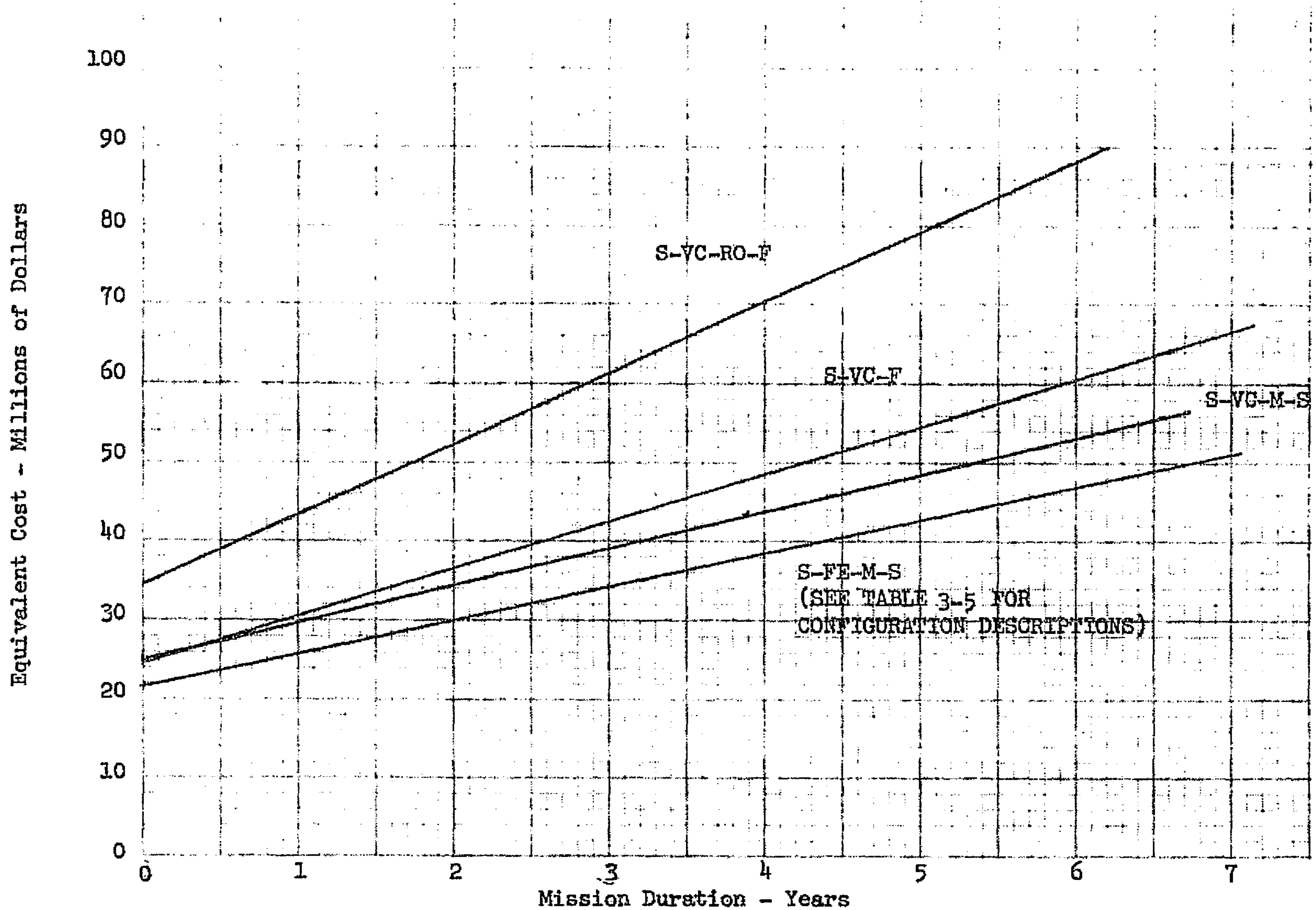

FIGURE 4-4 COST TRADEOFF FOR CANDIDATE CONFIGURATION - SPACE STATION

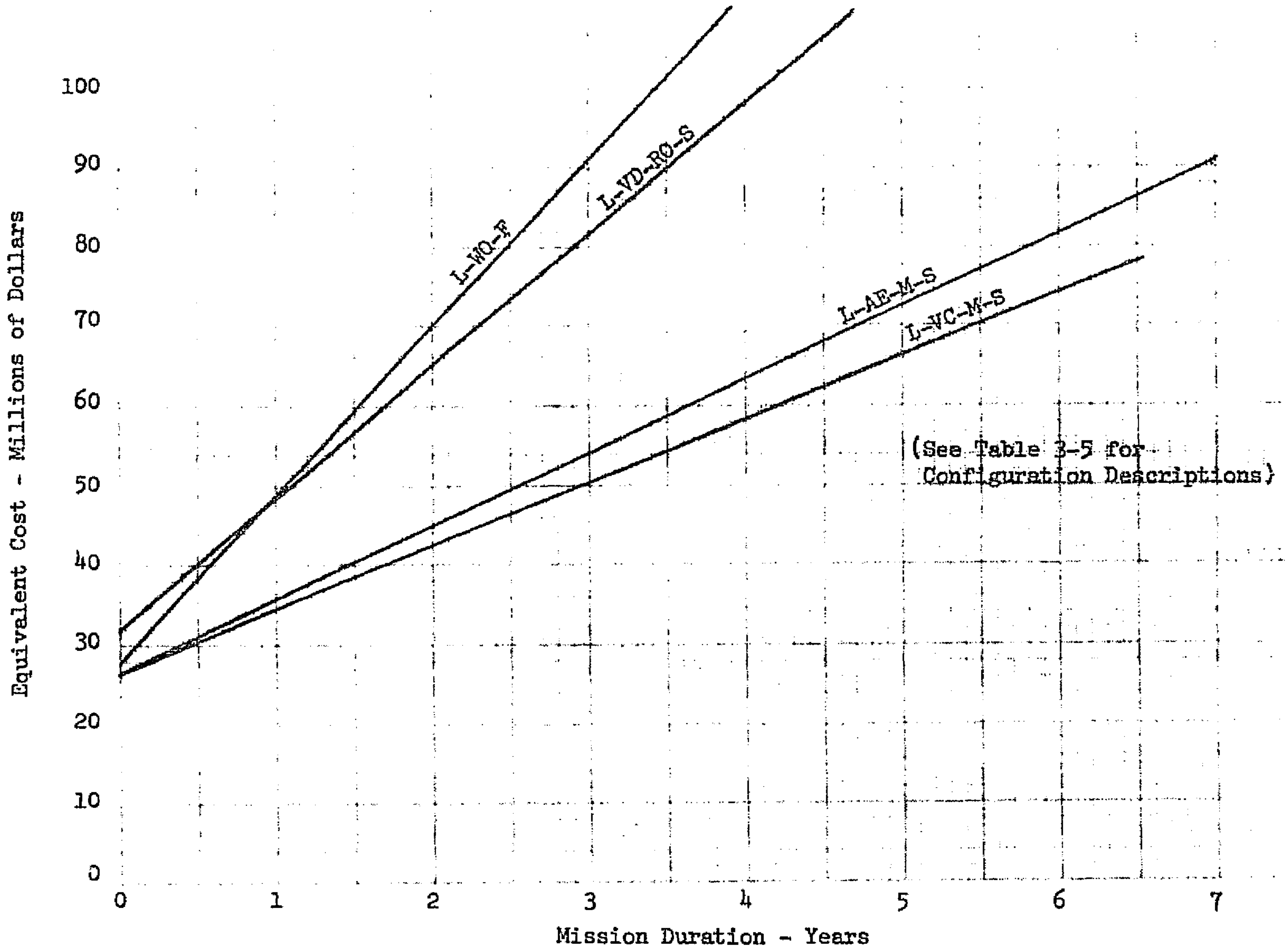

FIGURE 4-5 COST TRADEOFF FOR CANDIDATE CONFIGURATION - LUNAR BASE

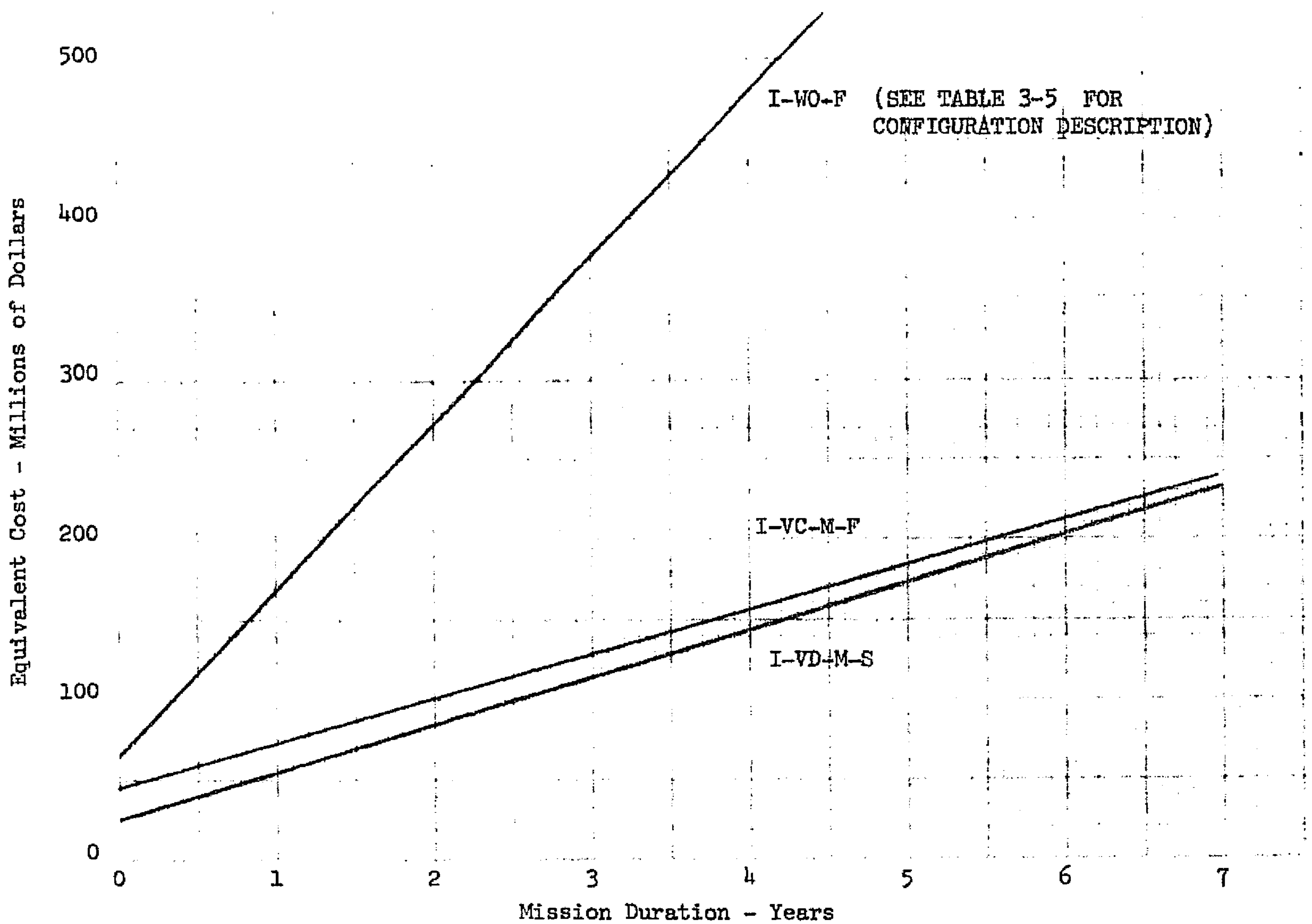

FIGURE 4-6 COST TRADEOFF FOR CANDIDATE CONFIGURATIONS - INTERPLANETARY

TABLE 4-3

COST SUMMARY FOR CANDIDATE CONFIGURATIONS

APPLICATION/FUNCTION		ITEM		Equivalent Cost ($x10^6) Initial	Equivalent Cost ($x10^6) 3 Year Total
SPACE STATION					
S-VC-RO-F	Urine water recovery	Vapor compression		15.27	22.15
	Wash water recovery	Reverse osmosis		10.12	23.56
	Waste management	Vacuum dry with flush		7.84	11.39
	Makeup water	Bladdered tanks		.85	4.06
			TOTAL	34.08	61.16
S-FE-M-S	Urine water recovery	Flash evaporator		12.21	16.85
	Wash water recovery	Multifiltration		5.40	9.77
	Waste management	Slinger vacuum dry		4.38	7.49
	Makeup water	Bladdered tanks		0	0
			TOTAL	21.99	34.11
S-VC-F	Urine and wash water recovery	Vapor compression		15.92	27.01
	Waste management	Vacuum dry with flush		7.84	11.39
	Makeup water	Bladdered tanks		.84	3.79
			TOTAL	24.60	42.19
S-VC-M-S	Urine water recovery	Vapor compression		15.21	21.79
	Wash water recovery	Multifiltration		5.40	9.77
	Waste Management	Slinger vacuum dry		4.38	7.49
	Makeup water	Bladdered Tanks		0	0
			TOTAL	24.99	39.05

TABLE 4-3 (continued)

COST SUMMARY FOR CANDIDATE CONFIGURATIONS

APPLICATION/FUNCTION		ITEM		Equivalent Cost ($\$x10^6$) Initial	Equivalent Cost ($\$x10^6$) 3 Year Total
LUNAR BASE					
L-AE-M-S	Urine water recovery	Air evaporation with electrolytic pretreatment		15.78	28.16
	Wash water recovery	Multifiltration		6.17	16.47
	Waste management	Slinger/vacuum dry		4.57	9.44
	Makeup water	Bladdered tanks		0	0
			TOTAL	26.52	54.07
L-VD-RO-S	Urine water recovery	Vapor diffusion		13.52	21.61
	Wash water recovery	Reverse osmosis		11.81	33.24
	Waste management	Slinger/vacuum drying		4.57	9.44
	Makeup water	Bladdered tanks		1.08	16.47
			TOTAL	30.98	80.76
L-WO-F	Urine and wash water recovery	Wet oxidation		16.84	41.97
	Waste management	Vacuum dry with flush		8.48	13.53
	Makeup water	Bladdered tanks		1.43	34.50
			TOTAL	26.75	90.00
L-VC-M-S	Urine water recovery	Vapor compression		16.04	24.15
	Wash water recovery	Multifiltration		6.17	16.47
	Waste management	Slinger vacuum dry		4.57	9.44
	Makeup water	Bladdered tanks		0	0
			TOTAL	26.78	50.06

TABLE 4-3 (continued)

COST SUMMARY FOR CANDIDATE CONFIGURATIONS

APPLICATION/FUNCTION		ITEM		Equivalent Cost ($\$ x 10^6$) Initial	Equivalent Cost ($\$ x 10^6$) 3 Year Total
INTERPLANETARY					
I-WO-F	Urine and wash water recovery	Wet oxidation		28.15	153.55
	Waste management	Vacuum dry with flush		12.35	27.42
	Makeup water	Bladdered tanks		25.41	198.64
			TOTAL	65.91	379.61
I-VD-M-S	Urine water recovery	Vapor diffusion		10.56	37.21
	Wash water recovery	Multifiltration		10.82	57.70
	Waste management	Slinger/vacuum drying		5.78	21.49
	Makeup water	Bladdered tanks		0	0
			TOTAL	27.16	116.4
I-VC-M-F	Urine water recovery	Vapor compression		22.28	45.71
	Wash water recovery	Multifiltration		10.82	57.70
	Waste management	Vacuum dry with flush		12.35	27.42
	Makeup water	Bladdered tanks		0	0
			TOTAL	45.45	130.83

From an equivalent weight standpoint, expendables and spares are the most influential factor followed by fixed equipment weight and power weight.

4.2 Qualitative Evaluations

A description of quantitative considerations was given in section 2.3 of this report. These considerations were used to restrict the number of candidate configurations (system combinations) selected in section 3.5; only concepts with the highest 3 rankings, qualitatively, were considered. In this section, the candiate configurations are compared on a combined system basis.

The qualitative evaluations for the configurations were obtained by assigning point values to the individual concept evaluations given in Table 3-4. Three points were given for high rating, two for medium and one for low. The values for the concepts making up each candidate configuration were averaged and then the appropriate rating high, medium or low was given to the configuration based on the resultant average point value. This was done for each candidate configuration and for each qualitative consideration. As an example, consider performance for S-VC-RO-F. If the point values are averaged for these concepts, 2.67 points result which is closest to a high rating. Thus, S-VC-RO-F is given a high rating in performance as seen in Table 4-4. This was done for all the candidate concepts shown in the table. The last column of table 4-4 shows the point totals based on three points for high, two points for medium and one point for low. A result of this evaluation shows that the highest rating results for concepts using vapor compression, multifiltration and slinger/vacuum drying, S-VC-M-S and L-VC-M-S. These concepts have six high ratings and one medium rating. The next best rating is for I-VC-M-F which has four high rating and three medium ratings.

TABLE 4-4

QUALITATIVE EVALUATION

WATER AND WASTE MANAGEMENT CANDIDATE CONFIGURATIONS

CANDIDATE CONFIGURATION	PERFORMANCE	SAFETY	DEVELOPMENT CONFIDENCE	FLEXIBILITY	GROWTH POTENTIAL	INTERFACE INSENSITIVITY	SIMPLICITY	POINT TOTALS
S-VC-RO-F	H	M	M	H	H	M	M	17
S-FE-M-S	H	H	M	M	M	M	M	16
S-VC-F	H	M	H	H	M	M	M	17
S-VC-M-S	H	H	H	H	M	H	H	20
L-AE-M-S	H	H	M	M	M	L	M	15
L-VD-RO-S	M	H	M	M	M	M	M	15
L-WO-F	M	M	L	H	H	L	M	14
L-VC-M-S	H	H	H	H	M	H	H	20
I-WO-F	M	M	L	H	H	L	M	14
I-VD-M-S	H	H	M	H	M	M	M	17
I-VC-M-F	H	H	H	H	M	M	M	18

H - HIGH RATING (3 points)

M - MEDIUM RATING (2 points)

L - LOW RATING (1 point)

4.3 Combined Evaluations

In this section, the combined evaluation is presented which includes the equivalent weight and cost and qualitative evaluations. This is summarized in Table 4-5. An additional concept has been added based on the results of Section 4.2 which is I-VC-M-S.

Upon examination of the table it can be seen that the configurations employing vapor compression, multifiltration and slinger/vacuum dry waste management are lowest in weight for 2 of the 3 applications. It also is lowest in cost for lunar base applications, second lowest cost for Space Station and Interplanetary, and first in qualitative ranking in all three applications.

A detailed examination of cost difference between S-FE-M-S and S-VC-M-S shows that the hardware cost for flash evaporation was lower than that for vapor compression.

Configuration L-VC-M-S was lower in cost than L-AE-M-S primarily due to higher resupply costs and power for air evaporation. These costs were partly but not fully offset by higher hardware costs of the vapor compression.

Much lower launch weights and hardware costs of I-VD-M-S made that configuration lower in cost than I-VC-M-S even though the vapor diffusion concept had a very high power cost.

It was clear from the results that configurations using multifiltration and slinger/vacuum dry concepts were superior in all applications and considering all criteria including weight, cost and qualitation considerations. Vapor compression ranked by far the best overall concept for urine water recovery considering the same criteria although it was not favored in two applications from a cost standpoint.

TABLE 4-5

CANDIDATE CONFIGURATION EVALUATIONS

CONSIDERING WEIGHT, COST AND QUALITATIVE CRITERIA

APPLICATION	RANKING OF BEST 4 CONFIGURATIONS				
	WEIGHT		COST		
	CONFIGURATION	AMOUNT HIGHER (LB)	CONFIGURATION	AMOUNT HIGHER (5×10^6)	QUALITATIVE
SPACE STATION	S-VC-M-S	0	S-FE-M-S	0	S-VC-M-S
	S-FE-M-S	373	S-VC-M-S	4.94	S-VC-F and S-VC-RO-F
	S-VC-F	5,557	S-VC-F	8.08	S-FE-M-S
	S-VC-RO-F	7,183	S-VC-RO-F	27.05	
LUNAR BASE	L-VC-M-S	0	L-VC-M-S	0	L-VC-M-S
	L-AE-M-S	2,524	L-AE-M-S	4.01	L-AE-M-S and L-VD-RO-S
	L-VD-RO-S	7,927	L-VD-RO-S	30.70	L-WO-F
	L-WO-F	17,583	L-WO-F	39.94	
INTERPLANETARY	I-VD-M-S	0	I-VD-M-S	0	I-VC-M-S
	I-VC-M-S	145	I-VC-M-S	3.08	I-VC-M-F
	I-VC-M-F	497	I-VC-M-F	14.43	I-VD-M-S
	I-WO-F	18,777	I-WO-F	263.21	

4.4 Water Quality Evaluation

There exists a considerable amount of psychological difficulty for one who has to consume water recovered from urine, feces, and wash water eventhough it is physically, chemically, and microbiologically "pure" according to certain standards established by various recognized scientific groups (e.g., NAS/NRC, NASA, U.S.P.H.S.). "Potable" water recovered from various sources of waste water (e.g., urine, feces, wash water) may be unpalatable because of the presence of some substance not considered in the standards, hence not detected. It may be unpalatable because of the mental association of the water to its origin. Thus, water recovered from urine, feces, and wash water must genuinely be of superior quality to overcome the psychological barrier. Poor quality water recovered from waste water has a very strong effect on the physical and psychological health of the crew. Dehydration and low morale will result from the crew's hesitancy to consume unpalatable water. Crews on long duration space missions are already under the stressful conditions of confinement and it does not take too much discomfort to precipitate crew related problems and compromised performance.

Thus far, the major emphasis on water recovery systems has been on system performance. Product water chemical composition analyses have not been thorough. Few developers of water recovery systems do the complete set of chemical analyses on those quantities called for in the SD-W-0020 specification which is currently recognized as the manned spacecraft water potability standards. But even specifications in SD-W-0020 is incomplete. For example, it does not mention the quantities of ammonia and urea which may very well be found in the water processed from urine and wash water. Urea is the predominant organic component in urine and ammonia results from the breakdown of urea by urease. Conductivity should also be included in the standards for it is a measurement easily adaptable to the zero-G environment and gives a gross indication of the ionic content of the water.

Water quality analysis has to be thorough and frequent. Experience has shown that the levels of certain quantities can vary widely, frequently exceeding the set limits. It is almost a certainty that a post-treatment system, such as multifiltration, will be necessary to consistently produce potable water that will meet all potability standards for any chosen system. Post-treatment has not been reflected in this trade study. It is assumed here that the product water is potable but it should be kept in mind that a system that produces unpalatable water could be uncompetitive from the performance standpoint due to the need to reprocess.

It must be noted that the following general comments made on product water quality are based on incomplete chemical analyses. Neither are the chemical analyses made according to a uniform standard so a quantitative comparison cannot be made. It is recommended that a frequency schedule for specification SD-W-0020 be instituted to give a better basis for a comparative water quality evaluation.

Vapor Compression (Reference 5)

Performance test has been made with urine only. The effect of wash water and fecal water on product water quality has not yet been determined. The Chemtric report published only 20 or so water samples with only 3 with complete water analysis. The pH in all cases were below the SD-W-0020 specified level of 6.0 which can be easily corrected with ion exchange columns. Silver content exceeded the specified level in most cases. Nickel, mercury, lead, and iron also exceeded their limits in significant number of instances. The general product water quality rating is good.

Flash Evaporation (Reference 24)

Product water from the flash evaporator was reported to have a strong odor. Hexavalent chromium and Iron levels were consistently exceeded. Only six of the samples were reported in Reference 24. pH was mainly on the high side but barely within the limit. Lead was not determined accurately enough

to determine if the limit has been exceeded. Only < 3 ppm was reported but the limits were 0.2 and 0.05 ppm using the 1967 AD Hoc panel and MSC-SPEC-35 standards. The nitrate level was exceeded once. The general rating is poor which is due mainly to the detectable odor.

Air Evaporation with Electrolytic Pretreatment (References 32 and 33)

The product water quality of the air evaporation system with electrolytic pretreatment is very good. It meets all the chemical and microbial specifications of SD-W-0020 except for pH which is generally low (between 4 and 6). Ammonia, which is not a SD-W-0020 standard, is generally high when compared to the NAS/NRC 1972 standards. Some urea analysis was also done but there is no standard with which to compare to. The product water from the electrolytically pretreated urine is remarkably free from microorganisms. In fact, the air evaporation unit which initially had microorganisms in its product water from processing chemically pretreated urine was free of microorganisms after processing with electrolytically pretreated urine. The product water remains sterile for all electrolytically pretreated water. Some concern is shown for the sterile nature of the product water and an investigation to see if it will be toxic when consumed has been initiated by NASA-JSC by feeding the product water to laboratory animals.

Air Evaporation with Chemical Pretreatment (Reference 34)

The product water from this method of urine recovery was actually consumed by human subjects on the 90 Day Test of a Regenerative Life Support System, 1971. With post-treatment and heat sterilization, this water was considered acceptable by the crew. Recent test (June 1974) with an advanced closed cycle air evaporation unit show the product water to exceed the NAS/NRC standards in foaming and ammonia. There was a single violation of the hexavalent chromium standard and gross microbial contamination was detected. This product water will need some method of microbial control which will compromise its competitive position. The water quality is considered acceptable.

Reverse Osmosis (Reference 12)

Water recovered by Reverse Osmosis generally meets the water quality standards recommended by the NAS/NRC advisory center on toxicology. There is more tolerance to poor quality wash water than poor quality potable water. The general rating is good.

Multifiltration (Reference 35)

Multifiltration recovery of wash water has been extensively tested. It was used in the 90 Day Test of a Regenerative Life Support System with notable success. The main problem with this system is microbial control which can impart an unpleasant odor to the wash water. The odor may be so objectionable that the crew will refuse to use it. The product water quality is generally good and there is no objection to its use if the microbial contamination can be controlled even if some of the chemical standards (e.g., specific conductivity, pH, NaCl) are not met. The use of heat for microbial control will compromise its competitiveness with other systems. The general rating of its product water is good.

Electrodialysis (Reference 36)

The following comments on product water quality is based on an electrolysis-electrodialysis water recovery from urine system. The chemical data for the potable water produced is from a 17 day continuous electrolysis-electrodialysis test conducted under contract NAS1-8954. All the physical properties specified by the NAS/NRC were analyzed for each sample. Only two of the chemical standards, TOC and TDS were done. The pH values were low, mostly below 6. It is suspected that more extensive chemical analysis and post-treatment be required before the product water achieves potability status. The general rating is poor due to incomplete analysis.

RITE (Reference 37)

Only 10 batches were reported in the ASME paper no. 71 Av-4. Feces, urine, wash water, respiration/perspiration, food, packets, wipes and paper were

processed. Twenty quantities were analyzed per NAS 1967 potability standards. The nitrate and nitrites were exceeded for most of the samples (7 out of 10). Silver analysis was not done. pH was low (between 2.5 to 3.4). Conductivity ranged from a high of 2100 to a low of 250. The microbial limit was violated 3 days with a count of 19, 12, and 11 per ml. The general rating is good.

Wet Oxidation (Reference 27)

This system processed feces and urine in bench tests and claims to be able to process miscellaneous "spacecraft wastes". Temperature above 530°F produced "high" quality water with rapid reduction in water quality at lower temperatures. The wet oxidation process produces a clear sterile salty effluent water that requires salt removal and charcoal filtration to make it potable. Excessive ammonia is produced in this process and a catalyst study has been underway to reduce the ammonia produced.

Vapor Diffusion (Reference 19)

The typical product water has been reported to be able to meet the 1967 SSB of the NAS standards of quality in a 90-day test period. The water quality can be generally rated to be good. This system can maintain sterile water conditions when challenged by microbial innoculation. The urine used in the test had to be pretreated with sulfuric acid and chromium trioxide to prevent ammonia formation and bacterial growth in the ratio of 5.5 ml/liter raw urine. Throughout the test, the pH had to be kept below 5 to insure good quality product water.

Section 5

CONCLUSIONS AND RECOMMENDATIONS

The conclusions reached in the study are highly dependent upon the basic data used such as weight, power, cost and expendables and upon the qualitative evaluations. Unfortunately, the characteristic data does not originate from a common base, in most cases, and is not derived based on equal requirements. Therefore only general conclusions can be drawn based on the sensitivity of the trades to the various cost and weight penalties. From a weight standpoint the following conclusions can be made. Expendable weight in most cases is the largest contributer to the overall weight. Next largest factor is due to fixed weight followed by power penalty. Weight penalties due to cooling are not normally significant.

Hardware costs, i.e., nonrecurring, recurring, spares and expendable, are the most important factors for Space Station application. Hardware costs are also important for Lunar Base but fixed and expendable launch costs and power costs become significant also. Fixed and expendable launch costs and power costs are even more important for interplanetary applications.

The manner in which the individual concepts are combined to synthesize the configurations is not important except that 1) resupply water adds significant cost and weight penalties and system concepts which recover sufficient water to eliminate resupply are highly favored and 2) if fecal flush is used, a concept such as vapor compression must be selected to allow recovery of flush water.

Considering equivalent weight, cost and qualitative considerations, the following results were noted regarding concepts. The most attractive concepts for urine water recovery are, vapor compression, flash evaporation and air evaporation with electrolytic pretreatment. For wash water recovery,

multifiltration appeared somewhat superior to reverse osmosis. Waste management studies showed the slinger/vacuum drying concept traded better than the vacuum dry with flush.

Vapor diffusion trades very favorably from a weight and cost standpoint and shows great potential based on data available to the study. It ranked poorly qualitatively, however, and more effort is needed to more fully examine its potential.

Wet oxidation also has great potential because of its ability to process many kinds of waste which was not fully accounted for in the study.

Configurations which traded favorably are as follows for each application.

Application	Urine Recovery	Wash Water Recovery	Waste Management
Space Station			
S-VC-M-S	Vapor Compression	Multifiltration	Slinger/Vacuum Dry
S-FE-M-S	Flash Evaporation	Multifiltration	Slinger/Vacuum Dry
Lunar Base			
L-VC-M-S	Vapor Compression	Multifiltration	Slinger/Vacuum Dry
L-AE-M-S	Air Evaporation EPT	Multifiltration	Slinger/Vacuum Dry
Interplanetary			
I-VD-M-S	Vapor Diffusion	Multifiltration	Slinger/Vacuum Dry
I-VC-M-S	Vapor Compression	Multifiltration	Slinger/Vacuum Dry

Concepts using air evaporation are competitive but slightly more costly for all applications largely because of resupply requirements. Power costs for the Interplanetary mission also increases the costs for air evaporation even though free waste heat is available. These results apply to air evaporation with chemical pretreatment or electrolytic pretreatment.

The study surfaced information which leads to a number of specific recommendations as follows. Since hardware costs and development confidence are such important parameters, the concepts which have received substantial SRT effort in the past and rank high in the study should continue to be developed. This applied especially to vapor compression, flash evaporation, air evaporation, and multifiltration. Other concepts currently being developed should be examined in more detail to assess their ultimate and likely potential before additional funds are expended.

The task of evaluating water and waste management concepts should be a continuous effort and to make this effort more effective, the following recommendations are made:

1. Flight weight estimates of hardware, equipment, spares and expendables should originate from a common set of ground rules.
2. Standardized testing procedures for water quality should be followed by all contractors so a more accurate assessment of performance can be made.
3. Uniform costing methodology should be followed for hardware nonrecurring and recurring so that more accurate relative costs can be obtained.
4. An improved method of qualitative evaluation is needed based on specific go-no-go criteria.

SECTION 6

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APPENDIX A

DETAILED CALCULATION RESULTS

This appendix contains the detailed tradeoff data for cost and weight calculations for all concepts and configuration candidates considered in the study. "Concept" refers to the methods of processing urine, flush water, wash water and feces. "Configuration" refers to the combination of concepts when they have been combined into a system for water and waste management. The data allows the reader to examine the detailed contributing cost and weight elements in the trades for sensitivity analyses. It also enables the reader to perform trades on configurations other than those considered in this report.

TABLE A-1. CON T INITIAL WEIGHT

CONCEPT	PROCESS* MATERIAL	Space Sta.	Lunar Base	Interplan.	INITIAL WEIGHTS (LBS) FIXED & 90-DAY SPARES	POWER	LIQUID COOLING	AIR COOLING	TOTAL INITIAL
VAPOR COMPRESSION	U	X			459	46	--	7.7	513
			X		459	43	--	8.3	510
				X	459	42	--	7.2	508
	U + FW	X			552	68	--	11.5	632
			X		552	64	--	12.3	628
				X	552	63	--	10.6	626
	U + WW	X			1341	461	--	77.3	1879
			X		1341	433	--	82.8	1857
				X	1341	422	--	71.4	1834
	U + FW + WW	X			1371	483	--	81.0	1935
			X		1371	454	--	86.8	1912
				X	1371	443	--	74.8	1889
AIR EVAPORATION WITH ELECTROLYTIC PRETREATMENT	U	X			898	406	20.6	34	1359
			X		898	230	23.1	36	1187
				X	898	224	17.9	31	1171
AIR EVAPORATION WITH CHEMICAL PRETREATMENT	U	X			547	241	20.6	6.2	815
			X		547	77	23.1	6.6	654
				X	547	75	17.9	5.7	646

TABLE A-1. CONCEPT INITIAL WEIGHT

CONCEPT	PROCESS* MATERIAL	Space Sta.	Lunar Base	Interplan.	INITIAL WEIGHTS (LBS) FIXED & 90-DAY SPARES	POWER	LIQUID COOLING	AIR COOLING	TOTAL INITIAL
REVERSE OSMOSIS	WW	X			541	58	--	10	609
			X		541	54	--	10	605
				X	541	53	--	9	603
MULTIFILTRATION	WW	X			412	16	--	2.7	431
			X		412	15	--	2.9	430
				X	412	15	--	2.5	430
VAPOR DIFFUSION	U	X			162	299	21	15	497
			X		162	281	23	16	482
				X	162	274	18	14	468
ELECTRODIALYSIS	U	X			113	10	--	2	125
			X		113	10	--	2	125
				X	113	10	--	2	125
	U + W	X			608	73	--	12	693
			X		608	68	--	13	689
				X	608	66		11	685
FLASH EVAPORATION	U	X			290	122	--	20	432
			X		290	114	--	22	426
				X	290	112	--	18	420
	U + W	X			1368	622	--	104	2094
			X		1368	586		112	2066
				X	1368	570	--	96	2034

CONCEPT	PROCESS* MATERIAL	Space Sta.	Lunar Base	Interplan.	INITIAL WEIGHTS (LBS) FIXED & 90-DAY SPARES	POWER	LIQUID COOLING	AIR COOLING	TOTAL INITIAL
WET OXIDATION	U	X			242	96	21	2	361
			X		242	91	23	2	358
				X	242	88	18	2	350
	U + FW	X			315	141	31	2	489
			X		315	133	35	3	486
				X	315	130	27	2	474
	U + WW	X			691	921	208	15	1835
			X		691	867	232	17	1807
				X	691	845	180	14	1730
	ALL	X			712	966	218	16	1912
			X		712	909	244	17	1882
				X	712	886	189	15	1802
RITE	U	X			532	105	21	2	660
			X		532	99	23	2	656
				X	532	96	18	2	648
	U + FW	X			1112	154	31	3	1300
			X		1112	145	35	3	1295
				X	1112	142	27	2	1283

CONCEPT	PROCESS* MATERIAL	Space Sta.	Lunar Base	Interplan.	INITIAL WEIGHTS (LBS) FIXED & 90-DAY SPARES	POWER	LIQUID COOLING	AIR COOLING	TOTAL INITIAL
RITE (CONT)	U + WW	X			4033	1007	208	17	5265
			X		4033	948	232	18	5231
				X	4033	924	180	16	5153
	ALL	X			4167	1061	218	18	5464
			X		4167	999	244	19	5429
				X	4167	973	189	16	5345
BAG/STORAGE	F	X			211	1.5	0	0.25	213
			X		211	1.4	0	0.27	213
						1.4	0	0.23	213
VACUUM DRYING	F	X			285	3.0	0	0.50	289
			X		285	2.8	0	0.54	288
				X	285	2.7	0	0.46	288
SLINGER TYPE	F	X			105	9.3	0	1.56	116
			X		105	8.8	0	1.67	115
				X	105	8.5	0	1.44	115
VACUUM DRY WITH FLUSH	F	X			336	35.7	0	6.00	378
			X		336	33.6	0	6.43	376
				X	336	32.7	0	5.54	374

* F - Feces
U - Urine
FW - Flush Water
WW - Wash Water

TABLE A-2 CONCEPT WEIGHT INCREASE - 3 YEAR MISSION

Concept	Process Material*	Space Sta.	Lunar Base	Interplan.	INCREASE IN WEIGHT (LBS) Expendables & Spares	Power	Liquid Cooling	Air Cooling	Total Weight Increase	Total Weight for 3 Year Mission (lb.)
VAPOR DIFFUSION	U	X			163	574	22	67	826	1323
			X		163	285	16	44	508	990
				X	163	285	12	42	502	970
ELECTROLYSIS	U	X			1679	20	0	8	1707	1832
			X		1679	10	0	5	1694	1819
				X	1679	10	0	5	1694	1819
	U + W	X			7839	139	0	53	8031	8724
			X		7839	69	0	35	7943	8632
				X	7839	69	0	33	7941	8626
FLASH EVAPORATION	U	X			798	233	0	88	1119	1551
			X		798	116	0	58	972	1398
				X	798	116	0	56	970	1390
	U + WW	X			3684	1195	0	453	5332	7426
			X		3684	592	0	297	4573	6639
				X	3684	592	0	285	4561	6595
WET OXIDATION	U	X			1038	185	22	7	1252	1613
			X		1038	92	16	5	1151	1509
				X	1038	92	12	4	1146	1620
	U + FW	X			1491	271	33	10	1805	2294
			X		1491	134	24	7	1656	2142
				X	1491	134	18	7	1650	2124
	U + WW	X			4335	1769	225	67	6396	8231
			X		4335	877	159	44	5415	7222
				X	4335	877	119	42	5373	7103
	ALL	X			4524	1854	236	70	6684	8596
			X		4524	919	166	46	5655	7537
				X	4524	919	125	44	5612	7414

TABLE A-2 CONCEPT WEIGHT INCREASE - 3 YEAR MISSION

Concept	Process* Material	Space Sta.	Lunar Base	Interplan.	INCREASE IN WEIGHT (LBS) Expendables & Spares	Power	Liquid Cooling	Air Cooling	Total Weight Increase	Total Weight for 3 Year Mission (lb.)
VAPOR COMPRESSION	U	X			542	89	0	34	665	1178
			X		542	44	0	22	608	1118
				X	542	44	0	21	607	1115
	U + FW	X			680	131	0	50	861	1493
			X		680	65	0	33	778	1406
				X	680	65	0	31	776	1402
	U + WW	X			1732	884	0	325	2941	4820
			X		1732	438	0	220	2390	4247
				X	1732	438	0	211	2381	4215
	U + FW + WW	X			1779	927	0	351	3057	4992
			X		1779	459	0	231	2469	4381
				X	1779	459	0	221	2459	4348
AIR EVAPORATION WITH ELECTROLYTIC PRETREATMENT	U	X			2064	968	22	218	3272	4631
			X		2064	232	16	143	2455	3642
				X	2064	232	12	137	2445	3616
AIR EVAPORATION WITH CHEMICAL PRETREATMENT	U	X			1740	464	22	27	2253	3068
			X		1740	78	16	18	1852	2506
				X	1740	78	12	17	1847	2493
REVERSE OSMOSIS	WW	X			3936	111	0	42	4089	4698
			X		3936	55	0	28	4019	4624
				X	3936	55	0	26	4017	4620
MULTIFILTRATION	WW	X			2790	31	0	12	2833	3264
			X		2790	11	0	8	2809	3239
				X	2790	11	0	8	2809	3239

TABLE A-2 CONCEPT WEIGHT INCREASE - 3 YEAR MISSION

Concept	Process Material*	Space Sta.	Lunar Base	Interplan.	INCREASE IN WEIGHT (LBS) Expendables & Spares	Power	Liquid Cooling	Air Cooling	Total Weight Increase	Total Weight for 3 Year Mission (lb.)
RITE	U	X			1755	201	22	8	1986	2646
			X		1755	100	16	5	1876	2532
				X	1755	100	12	5	1872	2520
	U + FW	X			2436	296	33	11	2776	4076
			X		2436	146	24	7	2613	3908
				X	2436	146	18	7	2607	3890
	U + WW	X			7740	1934	225	73	9972	15237
			X		7740	959	159	48	8906	14137
				X	7740	959	119	46	8864	14017
	ALL	X			8229	2037	236	77	10579	16043
			X		8229	1010	166	51	9456	14885
				X	8229	1010	125	49	9413	14758
BAG/STORAGE	F	X			3012	2.9	0	1.08	3016	3229
			X		3012	1.4	0	.71	3014	3227
				X	3012	1.4	0	.68	3014	3227
VACUUM DRYING	F	X			744	5.7	0	2.16	751.9	1041
			X		744	2.8	0	1.42	748.2	1036
				X	744	2.8	0	1.37	748.2	1036
SLINGER TYPE	F	X			537	17.9	0	6.76	561.7	678
			X		537	8.9	0	4.44	550.3	665
				X	537	8.9	0	4.27	550.2	665
VACUUM DRY WITH FLUSH	F	X			306	68.5	0	26.0	400.5	779
			X		306	34	0	17.1	357.1	733
				X	306	34	0	16.4	356.4	730

* F - FECES
U - URINE
FW - FLUSH WATER
WW - WASH WATER

TABLE A-3. COST TR[illegible] DATA - INITIAL LAUNCH

CONCEPT	PROCESS* MATERIAL	Space Sta.	Lunar Base	Interplan.	INITIAL COSTS (MILLIONS OF DOLLARS)					INITIAL COST TOTA[illegible]
					Launch Weight	Launch Volume	HARDWARE			
							Non-recurring	Recurring	Initial Spares	
VAPOR COMPRESSION	U	X			0.285	0.021	7.6	6.9	.4	15.21
			X		1.093	0.047	7.6	6.9	.4	16.04
				X	5.100	0.345	7.6	6.9	.4	20.35
	U + FW	X			0.344	0.028	7.6	6.9	.4	15.27
			X		1.320	0.062	7.6	6.9	.4	16.28
				X	6.920	0.455	7.6	6.9	.4	22.28
	U + WW	X			0.865	0.138	7.6	6.9	.4	15.90
			X		3.332	0.293	7.6	6.9	.4	18.53
				X	17.540	2.154	7.6	6.9	.4	34.59
	U + FW + WW	X			0.886	0.137	7.6	6.9	.4	15.92
			X		3.412	0.303	7.6	6.9	.4	18.62
				X	17.770	2.220	7.6	6.9	.4	34.89
AIR EVAP WITH ELECTROLYTIC PRETREATMENT	U	X			0.581	0.090	9.8	3.3	.245	14.016
			X		2.239	0.198	9.8	3.3	.245	15.782
				X	11.636	1.456	9.8	3.3	.245	26.437
AIR EVAP WITH CHEMICAL PRETREATMENT	U	X			0.350	0.079	6.7	3.0	.724	10.85
			X		1.350	0.174	6.7	3.0	.724	11.948
				X	7.016	1.278	6.7	3.0	.724	18.72

TABLE A-3. COST TRADE DATA - INITIAL LAUNCH

CONCEPT	PROCESS* MATERIAL	Space Sta.	Lunar Base	Interplan.	INITIAL COSTS (MILLIONS OF DOLLARS) Launch Weight	Launch Volume	HARDWARE Non-recurring	HARDWARE Recurring	Initial Spares	INITIAL COST TOTAL
REVERSE OSMOSIS	WW	X			0.336	0.035	6.9	2.10	0.75	10.120
			X		1.289	0.770	6.9	2.10	0.75	11.809
				X	6.758	0.562	6.9	2.10	0.75	17.069
MULTIFILTRATION	WW	X			0.243	0.038	3.3	1.71	0.11	5.401
			X		0.971	0.083	3.3	1.71	0.11	6.174
				X	5.099	0.612	3.3	1.71	0.11	10.821
VAPOR DIFFUSION	U	X			0.121	0.010	5.19	2.55	0.28	8.151
			X		5.476	0.022	5.19	2.55	0.28	13.518
				X	2.380	0.164	5.19	2.55	0.28	10.564
ELECTRODIALYSIS	U	X			0.070	0.008	7.50	7.20	0.90	15.678
			X		0.269	0.017	7.50	7.20	0.90	15.886
				X	1.410	0.123	7.50	7.20	0.90	17.133
	U + WW	X			0.378	0.059	7.50	7.20	0.90	16.037
			X		1.453	0.129	7.50	7.20	0.90	17.182
				X	7.610	0.950	7.50	7.20	0.90	24.160
FLASH EVAPORATION	U	X			0.189	0.020	6.40	4.80	0.80	12.209
			X		0.730	0.045	6.40	4.80	0.80	12.775
				X	3.784	0.330	6.40	4.80	0.80	16.114
	U + WW	X			0.898	0.088	6.40	4.80	0.80	12.986
			X		3.463	0.195	6.40	4.80	0.80	15.658
				X	18.000	1.430	6.40	4.80	0.80	31.430

TABLE A-3. COST TRADE DATA - INITIAL LAUNCH

CONCEPT	PROCESS* MATERIAL	Space Sta.	Lunar Base	Interplan.	INITIAL COSTS (MILLIONS OF DOLLARS) Launch Weight	Launch Volume	HARDWARE Non-recurring	HARDWARE Recurring	HARDWARE Initial Spares	INITIAL COST TOTALS
WET OXIDATION	U	X			0.162	0.039	8.0	6.0	0.19	14.391
			X		0.625	0.086	8.0	6.0	0.19	14.901
				X	3.220	0.634	8.0	6.0	0.19	18.044
	U + FW	X			0.212	0.050	8.0	6.0	0.19	14.452
			X		0.826	0.111	8.0	6.0	0.19	15.127
				X	4.230	0.813	8.0	6.0	0.19	19.233
	U + WW	X			0.558	0.162	8.0	6.0	0.19	14.910
			X		2.200	0.358	8.0	6.0	0.19	16.748
				X	10.870	2.630	8.0	6.0	0.19	27.690
	ALL	X			0.577	0.167	8.0	6.0	0.19	14.934
			X		2.277	0.369	8.0	6.0	0.19	16.836
				X	11.250	2.707	8.0	6.0	0.19	28.147
RITE	U	X			0.339	0.054	10.6	5.28	0.14	16.413
			X		1.303	0.119	10.6	5.28	0.14	17.442
				X	8.010	0.870	10.6	5.28	0.14	24.900
	U + FW	X			0.699	0.069	10.6	5.28	0.14	16.788
			X		2.691	0.153	10.6	5.28	0.14	18.864
				X	14.017	1.123	10.6	5.28	0.14	31.160

CONCEPT	PROCESS* MATERIAL	Space Sta.	Lunar Base	Interplan.	INITIAL COSTS (MILLIONS OF DOLLARS) Launch Weight	Launch Volume	HARDWARE Non-recurring	HARDWARE Recurring	Initial Spares	INITIAL COST TOTALS
RITE (CONT)	U + WW	X			2.600	0.230	10.6	5.28	0.14	18.850
			X		10.022	0.507	10.6	5.28	0.14	26.549
				X	51.960	3.720	10.6	5.28	0.14	71.700
	ALL	X			2.690	0.240	10.6	5.28	0.14	18.950
			X		10.366	0.522	10.6	5.28	0.14	26.908
				X	53.720	3.830	10.6	5.28	0.14	73.570
BAG/STORAGE	F	X			0.129	0.021	2.3	5.28	0.14	7.870
			X		0.494	0.046	2.3	5.28	0.14	8.260
				X	2.600	0.340	2.3	5.28	0.14	10.660
VACUUM DRYING	F	X			0.172	0.028	4.8	3.30	0.30	8.600
			X		0.668	0.062	4.8	3.30	0.30	9.130
				X	3.508	0.457	4.8	3.30	0.30	12.370
SLINGER TYPE	F	X			0.069	0.011	3.2	1.05	0.05	4.380
			X		0.249	0.023	3.2	1.05	0.05	4.572
				X	1.310	0.170	3.2	1.05	0.05	5.780
VACUUM DRY WITH FLUSH	F	X			0.206	0.034	2.7	4.80	0.10	7.840
			X		0.800	0.075	2.7	4.80	0.10	8.475
				X	4.201	0.547	2.7	4.80	0.10	12.350

F - Feces
U - Urine
FW - Flush Water
WW - Wash Water

TABLE A-4 COST TRADE DATA - 3 YEAR MISSION INCREASE

Concept	Process Material*	Space Sta.	Lunar Base	Interplan.	3 YEAR COST INCREASE (MILLIONS OF DOLLARS) Resupply Weight	Resupply Volume	Power	Crew Time	Spares & Expendables	Total 3 Year Increase	Total Cos[t] 3 Year Mission
VAPOR COMPRESSION	U	X			.33	.107	.370	.977	4.8	6.58	21.79
			X		1.268	0.118	0.506	1.418	4.8	8.11	24.15
				X	6.66	1.736	2.785	3.959	4.8	19.94	40.29
	U + FW	X			.415	.134	.549	.977	4.8	6.88	22.15
			X		1.591	.148	0.751	1.418	4.8	8.71	24.99
				X	8.36	2.178	4.133	3.959	4.8	23.43	45.71
	U + WW	X			1.06	.342	3.694	.977	4.8	10.87	26.77
			X		4.053	0.379	5.050	1.418	4.8	15.70	34.23
				X	21.27	5.541	27.809	3.959	4.8	63.38	97.97
	U + FW + WW	X			1.09	.351	3.873	.977	4.8	11.09	27.01
			X		4.163	0.388	5.295	1.418	4.8	16.06	34.68
				X	21.8	5.69	29.157	3.959	4.8	64.41	100.3
AIR EVAPORATION WITH ELECTROLYTIC PRETREATMENT	U	X			1.259	.204	3.259	1.017	2.94	8.679	22.695
			X		4.830	0.450	2.676	1.477	2.94	12.373	28.155
				X	25.36	3.302	14.736	4.123	2.94	50.461	76.90
AIR EVAPORATION WITH CHEMICAL PRETREATMENT	U	X			1.06	.172	1.937	1.069	5.28	9.52	20.37
			X		4.072	0.379	0.897	1.552	5.28	12.18	24.128
				X	21.39	2.78	4.942	4.332	5.28	38.71	57.43
REVERSE OSMOSIS	WW	X			2.4	.389	.463	1.189	9.0	13.441	23.56
			X		9.210	0.858	0.632	1.726	9.0	21.426	33.235
				X	48.36	6.298	3.481	4.818	9.0	71.959	89.03
MULTIFILTRATION	WW	X			1.702	.276	.131	1.60	0.66	4.369	9.77
			X		6.529	0.608	0.179	2.323	0.66	10.299	16.473
				X	34.23	4.464	.988	6.485	0.66	44.877	57.7

TABLE A-4 COST TRADE DATA - 3 YEAR MISSION INCREASE

Concept	Process Mate-rial*	Space Sta.	Lunar Base	Interplan.	3 YEAR COST INCREASE (MILLIONS OF DOLLARS) Resupply Weight	Resupply Volume	Power	Crew Time	Spares & Expendables	Total 3 Year Increase	Total Cost 3 Year Mission
VAPOR DIFFUSION	U	X			0.099	0.016	2.399	0.739	3.326	6.579	14.73
			X		0.381	0.036	3.280	1.073	3.326	8.096	21.614
				X	2.003	0.261	18.060	2.995	3.326	26.645	37.21
ELECTRODIALYSIS	U	X			1.024	0.166	0.084	0.675	2.700	4.649	20.33
			X		3.929	0.366	0.114	0.980	2.700	8.089	23.975
				X	20.630	2.688	0.629	2.735	2.700	29.382	46.52
	U + WW	X			4.782	0.774	0.581	0.675	2.700	9.513	25.55
			X		18.343	1.709	0.795	0.980	2.700	24.527	41.71
				X	96.318	12.545	4.380	2.735	2.700	118.68	142.84
FLASH EVAPORATION	U	X			0.487	0.079	0.976	0.497	2.600	4.639	16.85
			X		1.867	0.174	1.334	0.722	2.600	6.697	19.47
				X	9.805	1.277	7.345	2.014	2.600	23.041	39.16
	U + WW	X			2.247	0.363	4.992	0.497	2.600	10.699	23.69
			X		8.621	0.802	6.824	0.722	2.600	19.569	35.227
				X	45.265	5.888	37.581	2.014	2.600	93.350	127.78
WET OXIDATION	U	X			0.633	0.103	0.773	0.493	2.250	4.252	18.64
			X		2.429	0.226	5.136	0.715	2.250	10.756	25.657
				X	12.753	1.661	5.818	1.997	2.250	24.479	42.52
	U + FW	X			0.910	0.147	1.134	0.493	2.250	4.934	19.39
			X		3.489	0.325	1.550	0.715	2.250	8.329	23.456
				X	18.320	2.387	8.536	1.997	2.250	33.490	52.72
	U + WW	X			2.644	0.429	7.391	0.493	2.250	13.207	28.12
			X		10.144	0.946	10.104	0.715	2.250	24.159	40.907
				X	53.264	6.944	55.641	1.997	2.250	120.096	147.786

TABLE A-4 COST TRADE DATA - 3 YEAR MISSION INCREASE

Concept	Process Material*	Space Sta.	Lunar Base	Interplan.	3 YEAR COST INCREASE (MILLIONS OF DOLLARS)						Total Cost 3 Year Mission
					Resupply Weight	Resupply Volume	Power	Crew Time	Spares & Expendables	Total 3 Year Increase	
WET OXIDATION (continued)	ALL	X			2.644	0.446	7.749	0.493	2.25	13.582	28.52
			X		10.586	0.985	10.593	0.715	2.25	25.129	41.965
				X	55.590	7.232	58.336	1.997	2.25	125.405	153.55
RITE	U	X			1.070	0.175	0.841	0.488	2.85	5.424	21.84
			X		4.107	0.387	1.150	0.709	2.85	9.203	26.645
				X	21.564	2.842	6.335	1.979	2.85	35.570	60.47
	U + FW	X			1.486	0.241	1.238	0.488	2.85	6.303	23.09
			X		5.700	0.531	1.693	0.709	2.85	11.483	30.347
				X	29.931	3.898	9.327	1.979	2.85	47.985	79.14
	U + WW	X			4.721	0.764	8.084	0.488	2.85	16.907	35.76
			X		18.112	1.687	11.050	0.709	2.85	34.408	60.957
				X	95.101	12.385	60.852	1.979	2.85	173.167	244.9
	ALL	X			5.020	0.812	8.513	0.488	2.85	17.683	36.63
			X		19.256	1.792	11.638	0.709	2.85	36.245	63.153
				X	101.110	13.153	64.087	1.979	2.85	186.179	256.8
BAG/STORAGE	F	X			1.837	0.298	0.012	1.157	1.68	4.984	12.85
			X		7.048	0.658	0.016	1.679	1.68	11.081	19.341
				X	37.008	4.832	0.090	4.688	1.68	48.298	58.96
VACUUM DRYING	F	X			0.454	0.073	0.024	2.656	3.6	6.807	15.41
			X		1.741	0.162	0.033	3.856	3.6	9.392	18.522
				X	9.14	1.190	0.180	10.76	3.6	24.87	37.24

TABLE A-4 COST TRADE DATA - 3 YEAR MISSION INCREASE

Concept	Process Mate-rial*	Space Sta.	Lunar Base	Interplan.	3 YEAR COST INCREASE (MILLIONS OF DOLLARS) Resupply Weight	Resupply Volume	Power	Crew Time	Spares & Expendables	Total 3 Year Increase	Total Cost 3 Year Mission
SLINGER TYPE	F	X			0.328	0.053	0.075	1.649	1.0	3.105	7.485
			X		1.257	0.117	0.102	2.395	1.0	4.871	9.443
				X	6.600	0.861	0.562	6.684	1.0	15.707	21.49
VACUUM DRY WITH FLUSH	F	X			0.187	0.030	0.286	1.842	1.2	3.545	11.39
			X		0.716	0.067	0.392	2.675	1.2	5.05	13.525
				X	3.760	0.490	2.156	7.466	1.2	15.072	27.42

* F - FECES
U - URINE
FW - FECAL WATER
WW - WASH WATER

TABLE A-5. WATER STORAGE WEIGHT DATA
CANDIDATE SYSTEM CONFIGURATIONS

CONCEPT	INITIAL LAUNCH FIXED WEIGHT + 90-DAY SPARES (LBS)	RESUPPLY WEIGHT - 3 YEARS (LBS)	TOTAL WEIGHT - 3 YEARS (LBS)
S-VC-RO-F	88	5245	5333
S-FE-M-S	0	0	0
S-VC-F	80	4826	4906
S-VC-M-S	0	0	0
L-AE-M-S	0	0	0
L-VD-RO-S	112	6558	6670
L-WO-F	236	14099	14335
L-VC-M-S	0	0	0
I-WO-F	1408	14099	15507
I-VD-M-S	0	0	0
I-VC-M-F	186	1873	2059
Open Water Concept Space Station	3510	409,320	413,000

TABLE A-6 WATER STORAGE COST DATA

CANDIDATE SYSTEM CONFIGURATIONS

Concept	INITIAL COST (MILLIONS OF DOLLARS) Launch Weight	Launch Volume	Hardware Cost	Total Initial	3 YEAR INCREASE (MILLIONS OF DOLLARS) Resupply Weight	Resupply Volume	3 Year Increase	Total Cost - End of 3 Years (Millions of Dollars)
S-VC-RO-F	.054	.014	.779	.847	3.20	.014	3.214	4.061
S-FE-M-S	0	0	0	0	0	0	0	0
S-VC-F	.049	.013	.778	.84	2.94	.013	2.953	3.793
S-VC-M-S	0	0	0	0	0	0	0	0
L-AE-M-S	0	0	0	0	0	0	0	0
L-VD-RO-S	0.262	0.039	.780	1.081	15.346	.039	15.385	16.466
L-WO-F	0.552	0.082	.794	1.428	32.992	.082	33.074	34.502
L-VC-M-S	0	0	0	0	0	0	0	0
I-WO-F	17.30	7.23	.882	25.41	173.23	0*	173.23	198.64
I-VD-M-S	0	0	0	0	0	0*	0	0
I-VC-M-F	2.285	.96	.787	4.032	23.01	0*	23.01	27.04
Open Water Concept Space Station	2.14	1.078	1.44	4.658	249.7	1.078	250.778	255.4

* Not resupplied - launched initially